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Evaluation Procedure	Deadline
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Review processing	2 weeks
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- Is the manuscript technically sound?
- Is the paper clearly written and well organized?
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Research on the Power Information Collector of Optical Fiber Based on EPON Technology

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Abstract—EPON(Ethernet Passive Optical Network) technology is a new kind of fiber optical broadband access network technology. The EPON system mainly includes OLT, ONU and ODN. It inherited the low cost of Ethernet and the high bandwidth of light network, so it has Broad prospects of application in the Residential electricity information collection fields. Based on above, this paper combines the characteristics of EPON technology and the requirement of information collection system in the Residential electricity, developed a design and application methods of Optical Fiber collection terminal equipment for the power consumption data acquisition system based on EPON technology, which is an important application part of EPON system. This paper mainly studies the hardware and software design of Optical Fiber collector, and its application in the Lain Xiang Community in Beijing.

Index Terms—EPON, ONU, Optical Fiber Collector, eCos System, Smart community

I. INTRODUCTION

EPON(Ethernet Passive Optical Network)is a new technology that adopts one-to-multi-points topology, realizes data transmission on the physical layer by optical fiber and optical passive devices, and provides various internet accesses by Ethernet. It is comprised of OLT (Optical Line Terminal), ONU (Optical Network Unit) on consumer side, and ODN (Optical Distribution Network), and can be flexibly organized into tree topology, star topology, bus topology, etc (e.g. [1]).

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EPON technology combines the advantages of both passive network and Ethernet technologies, with a transmission rate of both upstream and downstream reaching 1.25Gbps. It is featured with high-reliability, low maintenance cost, high compatibility with multiple topologies and interfaces, hence an ideal communication solution for the power system, which satisfies the unique requirements of network structure, security, maintainability and interface types for utilities.

Power consumption data collectors of traditional communication mode are well developed and widely applied. Collectors, concentrators and meters are integral parts of traditional power consumption data acquisition system. Differences between various solutions lie in the adoption of communication methods, such as GPRS, CDMA, RS485, carriers, and other integrated methods. The main problem regarding PLC is the rapid attenuation of high-frequency signal in low-voltage grids, while the GPRS and CDMA are affected by package loss, limited maximum rate, long switching delay, operation instability, uncertainty of fault processing time (e.g. [2]). The communication architecture of the system consists of two layers: one is communication between master station system and concentrators, called remote communication; the other is the communication between concentrators and meters, called local communication. Since the collecting points are numerous and collecting intervals short, large amount of data will come out. Thus it is ideal to adopt EPON optical fiber technology with broad bandwidth, low cost, and high scalability in the remote communication between master station system and concentrators to collect real-time, accurate and reliable power consumption data. In addition, EPON is compatible with current Ethernet technology, and can be easily maintained and managed. This paper focuses on the design and development of ONU, which is the key part of power consumption data acquisition system. By means of joint debugging of OLT and master station system, ONU has met its design requirements and SGCC (State Grid Corporation of China) standards.

II. OPERATING PRINCIPLE AND APPLICATION SOLUTIONS OF EPON SYSTEM

The EPON is the primary type of PON technology that reduces Optical Fibre deployment dramatically while preserving the merits of Ethernet networks. EPON is based on the IP/Ethernet structure. Currently, the IP/Ethernet implementation accounts for more than 95% of the total LAN

communications. With this cost-effective and efficient structure, the EPON becomes the most effective way to connect the end users to the access networks. The emergence of the 10 Gb/s Ethernet backbones and the metropolitan area rings also makes EPON the optimal last-mile solution of the future all-optical networks.

A. Operating Principle of EPON

In this paper, ONU refers to the equipment integrating traditional ONU and power consumption data collector, which is called optical fiber collector. Through single-mode bi-directional optical fiber, the upstream and downstream data of EPON has realized full-duplex communication by WDM (Wavelength Division Multiplexing) with a data rate of 1.25 G b/s. The downstream communication (from OLT to ONU) adopts TDM (Time Division Multiplex) broadcasting mode. The data is broadcasted from OLT down to all ONU by variable length information packet, and the maximum length of information packet can be 1518 bytes. Based on LLID (Logical Link Identifier), ONU receives packets that belongs to it and abandons other packets (e.g. [3]). The wave length of downstream communication is 1490 nm. The upstream communication shares the system by TDMA (Time Division Multiple Access). For each ONU upstream data, a private timeslot is allocated to ensure that only one ONU is sending upstream data at a time. The procedure is as follows: all data is marked with a unique LLID tag at ONU, then the OLT will allocate each registered ONU with a LLID tag, and finally the data is sent to OLT according to its timeslot. More details about the registration phase can be found in the current version of the IEEE 802.3ah standard as well as in [4]. The wave length of upstream communication is 1310nm.

transmit them to the users while others frames are discarded. The architecture of the EPON systems is illustrated in Fig.1 (e.g. [5]).

B. Application Solution

With optical fiber communication, the dedicated network of power system can be divided into two parts: the optical fiber backbone network and the optical fiber access network. The backbone network is comprised of SDH (Synchronous Digital Hierarchy) equipment, while the access network is comprised of EPON equipment. This article mainly focuses on the access network, which is directly applied in the local communication of power consumption data acquisition system.

In communities, as network-side equipment, OLT is both a switch or router and a multi-service platform which provides EPON-oriented optical interfaces. Besides the network assembling and access functions, OLT could also perform bandwidth assignments, network security and management configurations according to the customers' different QoS/SLA requirements. In electric power collection system OLT directly gets access to the acquisition server (master station system) by Ethernet in engine room, and works as a data bridge between master station system and ONU, providing PON interfaces for ONU, ODN is mainly composed of one or more passive optical splitters which connects OLT and ONU, and provides optical transmission channel between the two sides. It allocates the optical signal power, and split downstream signal from one fiber into several fibers and combine optical upstream signals from multiple fibres into one, the optical ratio can be 1:8, 1:16, or 1:32, and can be connected to each other. The longest distance the ODN can cover is 20 kilometres.

As the core part of power consumption acquisition system, ONU reach meters through RS485 bus, and collects power consumption information of end users. At present, each ONU can collect data from 32 meters, and its basic functions are in line with the specifications of SGCC. In a power consumption acquisition program based on EPON (e.g. Fig. 2), ONU collector refers to the power optical Fibre collecting equipment.

III. H&S DESIGN OF ONU

ONU adopts the idea of embedded and modular design. Compared with upstream GPRS, CDMA and 230MHz dedicated network of traditional concentrators, ONU takes optical Fibre as its communication medium. This has greatly improved the timeliness, stability and security of meter reading, hence an essential difference from traditional concentrators in terms of hardware structure. This design is expected to reach the goal is that the throughput performance, in multi ONU case, the upstream is greater than 90%, the downstream is greater than 95%; The overload packet loss rate, upstream is less than 10%, downstream is less than 5%; The forward delay, downstream is within 500us ,while the upstream within 1.5ms or less.

A. Hardware Design of the System

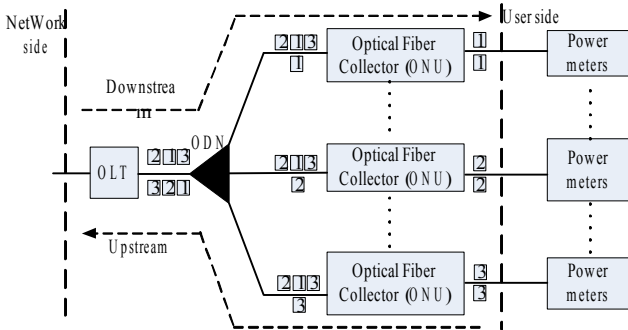


Fig. 1. Typical network diagram of EPON

As the branch-side equipment of EPON network, OLT aggregates data from ONU, which provides internet ports and other interfaces on consumer side. Each ONU transmits the customers' Ethernet frames to the OLT in the transmission timeslot which is assigned by the OLT. ODN is a 100% optical network of different topologies enabled by splitters of various split number and split ratio. EPON system adopts the broadcast method in downstream direction. Ethernet frames of different ONU are transmitted in one downstream timeslot. The packet which carries all the ONU data reaches different ONU and each ONU only extracts its own data frames and

The hardware of ONU mainly consists of 4 parts: EPON processor module, optical transceiver module, power supply module, FE interface module, bus and storage module (e.g. Fig. 3).

The core part of ONU is EPON processor module, which adopts the PCC8016 chip solution of CORTINA. This kind of chip is a single-chip solution functioned with traffic management and dispatching. It has built-in frame buffer,

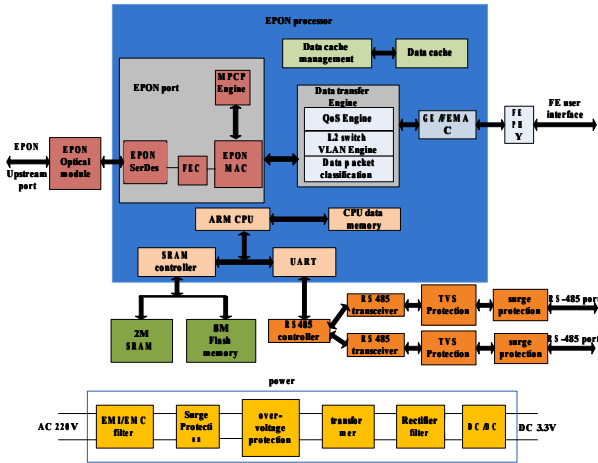


Fig. 3. Hardware schematic of Optical Fiber collector

Gigabit PON interface, serials port, JTAG debugging interface, FLASH and SRAM interfaces, and 5 volts power supply. And a built-in ARM-9 processor is responsible for management and control. As a standard IEEE 802.3ah compatible chip, it supports EPON Technological Specifications of China Telecom and MPCP (one-to-multi-points control protocol). The entire EPON system realizes the discovery and registration of ONU by means of MPCP Protocol (e.g. [6]). The operation principle of the MPCP mechanism can be explained as follows: the whole available upstream channel bandwidth is divided into transmission units (typically termed slots) using the Time Division Multiplexing (TDM) technique, which can be assigned to the active ONU (more specifically to the respective LLID) based on the DBA mechanism under operation in the OLT central packet schedule (e.g. [7], [8]). On consumer side, PCCS8016 also provides wide range of QoS (quality of service) and traffic management functions to guarantee that the bandwidth, delay, and jitter of each ONU are satisfied when the traffic is allocated by SLA. The optical module of this system adopts LTB34D2 and Optical transceiver provided by Hisense. The optical transmission distance of this module can reach 20 kilometers. The FE interface module for consumer business is a high speed Ethernet interface, which provides operation control platform for consumers and work as the debugging supporting interface for maintainers in the operation of ONU.

The Optical module of this system adopts LTB34D2 serials provided by Hisense. The Schematic of Optical transceiver is illustrated by Figure 4. The module incorporates 1310 nm burst-mode transmitter and 1490 nm continuous-mode receiver. An integrated WDM coupler can separate 1490nm

input laser light and 1310nm output laser light. The Optical transmission distance of this module can reach 20 kilometres. The FE interface module for consumer business is a high speed Ethernet interface, which provides operation control platform for consumers and work as the debugging supporting interface for maintainers in the operation of ONU.

In the process of power consumption data acquisition, as the core equipment, ONU receives meter-reading order from master station and handles it. The upstream communication uses optical fiber, while the downstream communication with meters uses RS485 bus.

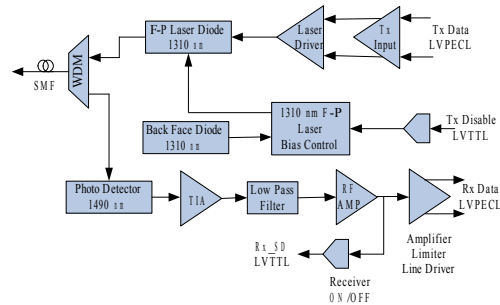


Fig. 4. Schematic of EPON Optical module

Tailored to the meter-reading system, a RS485 controller chip MAX3082 is added to the PCCS8016 processing chip to facilitate the switch from serial port to RS485 interface. For the bi-path RS485 interface, one path is used to connect RS485 BUS of meters; the other is used as engineering maintenance interface as well as meter connection. The extended FLASH is used to solidify the bootstrap and store data document of automatic meter reading. It is also functioned with data freezing, historical and curve data storage. The JS28F128 FLASH has a capacity of 16M, which basically meets application requirement. The SDRAM (HY57V1601 by HYNIX, 16M) is mainly used for operating system document copy from FLASH and caching of applications. The power supply module is also a key part of the system. It not only supports EMC, but also provides surge protection. With filter and transformer, it can provide a service voltage of 3.3 volts for the chip. In addition, the system has the function of hard clock. It uses the SD2405, high-accurate and real-time clock chip of built-in battery to realize the clock synchronization of the master station and collecting terminals of power consumption data acquisition system.

B. Software Design of the System

The software of ONU adopts embedded design idea. This article will skip protocols relating the upper layer OLT and focus on applications. Considering the real-time requirement of power consumption data acquisition system, the operating platform of ONU adopts the eCos (embedded Configurable operating system) by RedHat. This open source system is a configurable, portable, royalty-free, and real-time operating system for deeply embedded applications. Compared with Linux, the advantages of eCos lie in its flexible configurability, and less occupied kernel space, which makes it suitable for the

cost-sensitive terminals of power consumption data acquisition. Fig. 5 illustrates the software framework of the system. Similar to other embedded equipment, the bottom layer of the system as BSP (Board Support Package) are device drivers such as serial port, internet port, clock, FLASH, etc., enabling upper layer applications to access the hardware. The eCos realizes thread management, thread dispatch, interrupt and anomaly handling, and synchronization of the system on the platform layer.

According to the requirements of power consumption data acquisition system, the software adopts modular design. All the modules are independent threads, and communicate by message mechanism such as mailbox, queue and shared data structure. `Cys_user_start()`, the main function of applications,

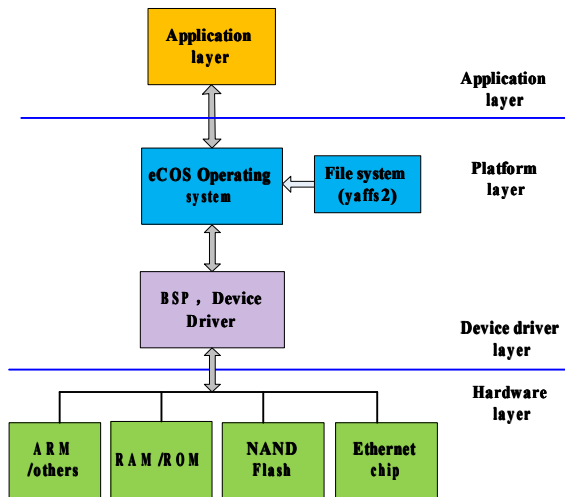


Fig. 5. Software diagram of Optical Fiber Collector

is responsible for creating main threads regarding to specific tasks, including:

- 1) *ONU_heart_thread and Task_thread*: Responsible for Freeze data of day, Freeze data of month and Freeze curve of meters for one month.
- 2) *Read_meter_rs485_thread*: Responsible for meter reading by collector at fixed intervals.
- 3) *Rx_thread and term_sever_rx_thread*: Responsible for sending data to RS485 meters from collectors and finish relevant protocol conversion.
- 4) *Protocol_Comm_thread*: Responsible for the protocol data analysis and processing for the master station and meters.
- 5) *Term_client_thread*: Responsible for the interaction between data and the master station.

All the threads are interdependent and compose the software of entire meter reading system.

IV. APPLICATION OF OPTICAL FIBER COLLECTORS IN SMART COMMUNITY

Smart community contains the power information collection, interactive services, residential distribution automatic, distributed power and energy storage of user side, electric vehicles charging, smart home furnishing and some new technological achievements. Smart community aims to achieve both economic growth and a low-carbon society. With this convenience community can achieve reliable power supply and the electricity consumption information is collected automatically. The smart community management system can promotes environmental quality improvement and energy saving in diverse urban activities. Optical Fibre Collectors make sure the power consumption information is real-time acquired and make some guides to there users.

A. Deployment of ONU Collectors

Deployment of optical Fibre collectors as the key of smart power consumption has been finished in Lain Xiang Community, the first smart community of commercial operation in Beijing.

Figure 6 illustrates the distribution of optical Fibre collectors in 2 buildings of Lain Xiang Community. About 20 collectors were installed; each of them covers 2 floors. Data from up to 700 meters is then time multiplexed by the splitter and transmitted to OLT and the master servers system in the basement. The master system can read meters at real time and store these data information into the local database, and the master station system can be connected to the public network.

Figure 7 shows an on-site installation of Optical Fibre Collector in Lain Xiang smart community. The Optical Fibre using OPLC (Optical Fibre Composite Low-voltage Cable) ensures high reliability of data transmission. With a smart home gateway, consumers can gain access to the database and

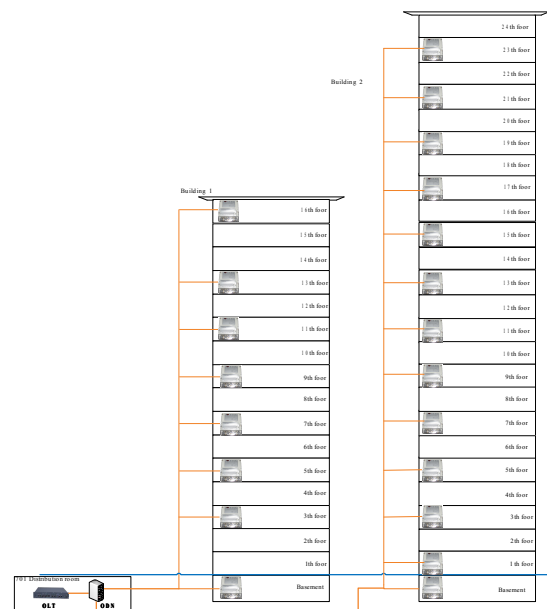


Fig. 6. Deployment diagram of Optical Fiber collector in the L.X.Y Community

check their daily or monthly power consumption information.

B. Comparison of Collection Success Rate

Collection success rate of meter reading system is the main purpose for electric power company, the ultimate goal is full coverage, full collection and full cost control. Base on above, the Optical Fibre Collectors arise at the historic moment. Table 1 show reading meters using Optical Fibre Collectors in

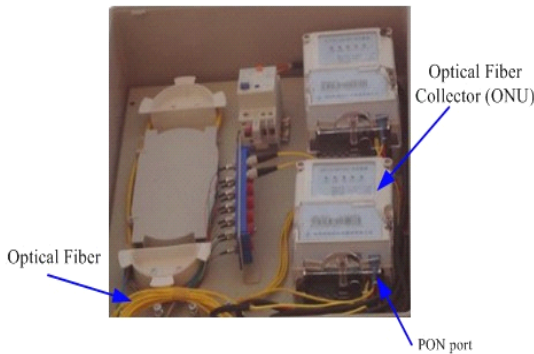


Fig. 7. On-site installation diagram in smart community

Lain Xiang community and table 2 shows reading meters using Power Line Carrier Collectors in Hue Xian community similar as Lain Xiang community, from November 1th. to 15th. In 2011. In the table user num refers to the meter numbers, collect num refers to the success reading numbers of meter, purchase num refers to the times of user purchase power, and sending num refers to the master station send purchase power data to the meters. Comparison between the two tables we can easily find the Optical Fibre Collectors have outstanding collect rate than the Power Line Carrier Collectors. This will be a trend by using ONU Collectors for electric power company make a choice for future Collector purchase and deployment.

TABLE 1. READING METERS USING OPTICAL FIBRE COLLECTORS

Date	Optical Fibre Collector (or ONU)					
	User Num	Collect Num	Collect Rate	Purchase Num	Sending Num	Sending Rate
11/1	694	694	100%	68	68	100%
11/2	694	693	99.9%	17	17	100%
11/3	694	694	100%	8	8	100%
11/4	694	694	100%	23	22	95.7%
11/5	694	694	100%	21	21	100%
11/6	694	694	100%	16	16	100%
11/7	694	694	100%	13	13	100%
11/8	694	694	100%	9	9	100%
11/9	694	694	100%	5	5	100%
11/1	694	694	100%	15	15	100%
11/1	694	694	100%	11	11	100%

TABLE 2. READING METERS USING POWER LINE CARRIER COLLECTORS

Date	Power Line Carrier Collector (or PLC)					
	User Num	Collect Num	Collect Rate	Purchase Num	Sending Num	Sending Rate
11/1	815	808	99.1%	9	6	66.6%
11/2	815	808	99.1%	13	13	100%
11/3	815	805	98.7%	13	13	100%
11/4	815	807	99.0%	9	7	77.7%
11/5	815	786	96.5%	13	10	76.9%
11/6	815	808	96.1%	10	9	90%
11/7	815	800	98.2%	8	7	87.5%
11/8	815	804	98.6%	11	11	100%
11/9	815	808	96.1%	12	11	91.6%
11/1	815	800	98.2%	7	6	85.7%
11/1	815	809	99.2%	15	15	100%

11/1	815	808	99.1%	9	6	66.6%
11/2	815	808	99.1%	13	13	100%
11/3	815	805	98.7%	13	13	100%
11/4	815	807	99.0%	9	7	77.7%
11/5	815	786	96.5%	13	10	76.9%
11/6	815	808	96.1%	10	9	90%
11/7	815	800	98.2%	8	7	87.5%
11/8	815	804	98.6%	11	11	100%
11/9	815	808	96.1%	12	11	91.6%
11/1	815	800	98.2%	7	6	85.7%
11/1	815	809	99.2%	15	15	100%

V. CONCLUSIONS

In this paper, we presented the development background of EPON technology, studied the development present situation and the application situation at home and abroad, and then proposed a new method for power information collection system using Optical Fibre Collector based on EPON technology. The implementation of power consumption information acquisition system is a vital part of smart grid construction, and is in line with the development of international grid technology. As a representative smart grid technology, power Fibre to home has been widely supported by the government and State Grid. Power Fibre communication network has covered more and more communities, providing residents with power consumption information acquisition services. Optical Fibre collectors based on EPON technology will be the mainstream of future power consumption information acquisition system.

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Performance Modeling and Evaluation of Millimeter-Wave Based WPANs

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Abstract—The large amount of unlicensed bandwidth available in the millimeter-wave has enabled very high data rate wireless applications. The IEEE 802.15 Task Group 3c has completed standardization efforts for multi-gigabit data rate communications on both the physical (PHY) and medium access control (MAC) layers. In this paper we use Performance Evaluation Process Algebra (PEPA) to evaluate a typical WPAN system's performance. The approach is more convenient, flexible, and lower cost than the former simulation method which needs develop special hardware and software tools. Moreover, we can easily analysis how changes in performance depend on changes in a particular modes by supplying ranges for parameter rate values.

Index Terms—WPAN, IEEE 802.15.3c, Performance Evaluation Process Algebra, Performance Analysis, Formal Modeling.

I. INTRODUCTION

WIRELESS system designers dream of replacing all cables for indoor data communication with high-speed wireless connections. Unfortunately, the dedicated unlicensed frequency spectrum for this purpose was insufficient until the U.S. Federal Communications Commission (FCC) declared that the 57-64 GHz band could be used. Japan, in turn, allocated the 59-66 GHz band. With the latest adoption of the European Telecommunications Standards Institute (ETSI) 57-66 GHz band, there is now a common continuous 5 GHz band available around 60 GHz in most of the major markets. As the wavelength of a signal at 60 GHz is around 5 mm, it is called millimeter wave (mmWave) band.

Another important breakthrough was the introduction of relative cheap and power-efficient complementary metal oxide semiconductor (CMOS) processing for semiconductor manufacturing of 60 GHz band devices. As a result, the price and power requirements for consumer devices were met. For successful commercialization, the final need for developers was a standard that would support almost all usage models.

The IEEE 802 LAN/MAN standards committee has many success stories in developing global wireless standards, such as 802.11 (WiFi) and 802.15.4 (Zigbee). Within IEEE 802, interest in developing an mmWave physical layer (PHY) began in July 2003, with the formation of an interest group under

802.15 working group for wireless personal area networks (WPANs). According to the IEEE 802 procedure, if the interest group is successful, it is followed by a study group, which decides the scope of the new standard. In March 2004, a study group for mmWave PHY was formally created. The study group members agreed that development for new PHY to transmit 1 Gb/s or higher data rates is feasible. It was decided to reuse an existing medium access control (MAC) layer (IEEE 802.15.3b), with necessary modifications and extensions. After the approval of the project authorization request, a task group was created. The task group first focused on creating usage models, a 60GHz indoor channel model, and evaluation criteria. After two years of hard work, three PHY modes and multiple MAC improvements were selected to support different usage models. After various letter ballots sponsor ballots, and resulting improvements, in September 2009 the IEEE-SA Standard Board approved IEEE 802.15.3c-2009 [1, 2]. It took four and a half years for the task group to complete the standard. Such a duration has been common for many IEEE standards that provided new PHYs.

The rest of this article explains the salient features of the standard, as well as some important outcomes. The organization of the article follows the order of the task group's standardization process. First, we provide channelization is explained, which is common for all PHY modes. Details of the three different PHY modes, new MAC layer features, and beamforming procedures are explained in the following sections, respectively. Moreover, we propose a framework for combined timed behaviors and stochastic process algebra. This done with a modeling language, called Performance Evaluation Process Algebra (PEPA), for describing the timed stochastic behaviors of wireless networks. This methodology can then be analyzed using an automatic tool. With this performance analysis methodology it is possible to obtain the design parameters of implementation using simulation with a lower computational time and cost.

II. PHY LAYER DESIGN IN 802.15.3C

Due to conflicting requirements of different usage models (UMs), three different PHY modes have been developed:

- Single carrier mode of the mmWave PHY (SC PHY)
- High-speed interface mode of mmWave PHY (HSI PHY)
- Audio/visual mode of the mmWave PHY (AV PHY)

The SC PHY is best suited for kiosk file downloading and office desktop usage models. The HSI PHY is designed mainly

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for the bidirectional, non-line-of-sight (NLOS), low-latency communication of the conference ad hoc model. The AV PHY is designed to provide high throughput for video signals in video streaming usage models. The main difference between the different PHYs is the modulation scheme. The SC PHY uses single carrier modulation, whereas the AV PHY and HSI PHY use the orthogonal frequency-division multiplexing (OFDM) modulation. In SC modulation, one symbol occupies the whole frequency band, and thus its duration is very short. In OFDM, the available frequency band is divided into orthogonal subcarriers, and data symbols are sent using those subcarriers. In general, SC modulation allows lower complexity and low power operation, whereas OFDM suits well in high spectral efficiency and NLOS channel conditions. Orthogonality of the subcarriers in OFDM allows the use of inverse fast Fourier transform (IFFT) at the transmitter and fast Fourier Transform (FFT) at the receiver.

All PHY modes have a typical signal frame format consisting of a preamble, header, and payload. The preamble is used for frame detection, channel estimation, frequency recovery, and time acquisition. The header contains essential information such as payload size, modulation, and coding used in the payload. The Payload includes the data to be transmitted.

A. Audio / Visual Mode of the mmWave PHY

As video and audio devices could be designed only as a wireless data source (e.g., DVD player) or only as a data sink (e.g., HDTV), highly asymmetric data transmission is possible; hence, the designers of the AV PHY mode created two different sub-PHY modes: high-rate PHY (HRP) for video transmission and low-rate PHY (LRP) for control signal. Both of the sub-PHY modes use OFDM.

The HRP mode has an FFT size of 512 and uses all the channel bandwidth available. There are three classes of modulation and coding schemes (MCSs) with equal error protection, delivering data rates of 0.952, 1.904, and 3.807 Gb/s. There are two MCSs with unequal error protection and two MCSs, in which only the most significant bits are sent.

On the other hand, the LRP mode occupies only 98 MHz bandwidth, and three LRPs are arranged per HRP channel. This allocation is to accommodate three different networks in one channel, because the HRP modes are assumed to have high beamforming gains.

The AV PHY use Reed-Solomon(RS) block code as the outer code and convolutional coding as the inner code in the HRP mode, whereas only convolutional coding is used in the LRP mode. Modulation schemes used in the AV PHY are limited to $\pi/2$ quadrature PSK (QPSK) and 16 quadrature amplitude modulation (QAM).

III. MAC LAYER ENHANCEMENTS OF 802.15.3C

Before going into the details of MAC layer enhancements, we briefly introduce the IEEE 802.15.3c MAC. It is based on the IEEE 802.15.3b standard, which itself is an improvement over IEEE 802.15.3. In the standard a network is called a piconet, which is formed in an ad hoc fashion. Among a group of devices (DEVs), one will act as the piconet coordinator

(PNC) to provide the piconet's synchronization and to manage access of rest of the DEVs. The necessary control information is embedded in beacons. Upon receiving a beacon from a PNC, the DEVs become aware of the existence of piconet. Beacons provide information about when and how DEVs can access the network.

During network operation, time is divided into sequential superframes (SFs). Each SF has three segments: a beacon period, a contention access period (CAP), and a channel time allocation period (CTAP). During the beacon period, the PNC sends one or multiple beacons. The CAP is reserved mainly for command and control communication between PNC and DEVs. Since such a communication is mainly asynchronous, a suitable access method is selected, carrier sense multiple access with collision avoidance (CSMA/CA). The remaining time of an SF includes the CTAP, which provides time-division multiple access (TDMA) communications. The CTAP is composed of multiple channel time allocations (CTAs). Each CTA is a time slot granted by the PNC for a certain pair of DEVs. Time-sensitive applications such as AV streaming use the CTAP for guaranteed data transmission. With these specifications, system designers had already developed an efficient and well structured MAC layer that only required improvements in three major areas:

- Providing coexistence among different PHYs and avoiding interference from hidden devices
- Improving transmission efficiency to enable MAC SAP rates over 1 Gb/s and providing low-latency transmission for delay-sensitive applications
- Supporting directivity inherent to 60 GHz signals and beamforming antennas

In the next two paragraphs, we explain enhancements in the first two areas.

To achieve better coexistence among DEVs using different PHY modes, a sync frame is introduced. A sync frame includes information about the duration of the SF and timing information of the CAP and each CTA. Sync frames are modulated using the common mode signaling (CMS) mentioned in the previous paragraph. According to 802.15.3c rules, it is mandatory for all PNC-capable DEVs to transmit a sync frame in every SF. In addition, any PNC-capable DEV shall be able to receive and decode sync frames and other command frames modulated with CMS.

As a result, any PNC-capable DEV, regardless of its PHY mode in operation, will be informed about the existence of nearby piconets. It will then have the opportunity to join one instead of starting another independent piconet. The sync frame transmission can thus be seen as an effective coexistence method to mitigate potential co-channel interference from other piconets. Apart from the rule for PNC-capable DEVs, an optional rule related to non-PNC-capable DEVs is also defined in the standard: Any DEV capable of transmitting a sync frame may do so in the first granted CTA in an SF and in every predefined number of SFs.

This rule is intended to further extend the coverage area of the sync frame. It allows non-PNC-capable DEVs to participate in the sync frame transmission.

In high-speed WPAN and WLAN systems transmission efficiency decreases with the increase in transmission speed due to the increased ratio of overhead time to payload transmission time. To improve transmission efficiency and throughput performance, frame aggregation can be employed. The basic idea of frame aggregation is to reduce the overhead, such as the preamble and PHY/MAC header, by concatenating multiple MAC service data units (MSDUs) to form a frame with a long payload. In the IEEE 802.15.3c standard, two novel aggregation methods are specified standard aggregation and low-latency aggregation.

Standard aggregation is designed to support transmission of uncompressed video streaming. The MAC layer of the transmitter, upon receiving an MSDU from the upper layer, divides the MSDU into small pieces of data blocks if the length of the MSDU exceeds a predefined threshold. This process is called fragmentation. The MAC attaches a frame check sequence (FCS) to each data block to form a subframe. For each subframe, there is a subheader (Sh) created to carry information needed for the receiver to decode individual subframes, such as subframe length, MSDU sequence number, and used MCS. The MAC header, on the other hand, carries high-level control information applicable to all the subframes, such as source and destination addresses. All the subheaders are placed back-to-back and attached to a single header check sequence (HCS) to form a MAC subheader. The MAC layer then transfers the subframes, MAC subheader, and MAC header to the PHY layer. The PHY layer performs channel coding and modulation, and delivers the data to the receiver over the wireless channel afterward. An important aspect of this method is that instead of distributing the subheaders between the subframes, all the subheader are concatenated and put in front of the subframes. The reason for such a design is that video streaming contains both data and control information, which should be treated with different priorities. Changing MCS over subframes is a common approach to support priority. However, when operating at a speed of gigabits per second, timely changing of the MCSs subframe by subframe can be difficult for the receiver. However, putting the subheaders in front enables the receiver to know the MCS of each subframe in advance, helping to realize timely MCS switching. It was reported that over 80 percent efficiency improvement and above 4 Gb/s throughput are achieved with standard aggregation.

IV. PERFORMANCE MODELING AND TOOLS

Performance Evaluation Process Algebra (PEPA), developed by Hillston in the 1990s [4, 5], is a timed and stochastic extension of classical process algebras such as Communication Sequential Process (CSP) [6]. It describes a system as an interaction of the components and these components engage in activities. Generally, components model the physical or logical elements of a system and activities characterize the behavior of these components. An exponentially-distributed random variable is associated with each activity specifies the duration of it, that leads to a clear relationship between the model and a Continuous Time Markov Chain (CTMC) process.

Via this underlying Markov process performance measures can be extracted from the model. The PEP A formalism provides a small set of operators which are able to express the individual activities of components as well as the interactions between them. We provide a brief summary of the operators here, more details about PEPA can be found in [3, 4].

Prefix: $(a, r).P$ The component will subsequently behave as P after it carries out the activity (a, r) , a represents the action type and r represents a duration which satisfies exponential distribution with parameter r .

Choice: $P + Q$ The component represents a system which may behave either as P or as Q . the choice depends on which activity is completed first.

Cooperation: $P \bowtie_{L_1} Q$ The component represents the interaction between P and Q . the set L is called the cooperation set and denotes a set of action types that must be carried out by P and Q together.

Probabilistic Choice: $P \oplus_r Q$ denotes the probabilistic choice with the conventional generative interpretation, thus with probability r the process behaves like P and with probability $1 - r$ it behaves like Q .

Hiding: P / L Hiding makes the activities whose action types in L invisible for external observer.

Constant: $P = Q$ The equation gives the constant P the behavior as the component Q .

A. PEPA Eclipse Plug-in Tools

The PEPA is a language for modelling systems in which a number of interacting components run in parallel, and whose behaviour is stochastic. The core semantics of PEPA is in terms of Continuous Time Markov Chains (CTMCs), and an alternative semantics in terms of Ordinary Differential Equations (ODEs) has also been developed. PEPA has been applied in practice to a wide variety of systems, and its success as a modelling language has been largely down to its extensive tool support. Most recently, the PEPA Plug-in Project [7, 8] has integrated a range of analysis techniques based on both numerical solution and simulation into a single tool built on top of the Eclipse platform [9]. As with all compositional Markovian formalisms, however, PEPA suffers from the state space explosion problem. A model can have an underlying state space that is exponentially larger than its description, meaning that it can be infeasible to analyse. Fluid flow approximation using PEPAs ODE semantics can solve this problem if we are only interested in the average behaviour of the system over time. However, if we want to reason over all possible behaviours of the model for example, the probability that an error occurs within some time interval then we must consider the CTMC semantics. In this paper, we present a new extension to the PEPA plugin, in which a model can be abstracted by combining, or aggregating, states. To safely over-approximate the behaviour of the original model (for any aggregation of its states), we use two abstraction techniques - abstract CTMCs (a type of Markov decision process with infinite branching), and stochastic bounds. We provide a model checker for the three-valued Continuous Stochastic Logic (CSL), which computes from the abstraction

a safe bound of the probability of a quantitative property holding in the original model X if the actual probability is p , then the model checker will return an interval $I = [p_1, p_2]$ such that $p \in I$. The current version of the PEPA plug-in is available from <http://www.dcs.ed.ac.uk/pepa/tools/plugin>, and provides several views:

Abstract Syntax Tree View

The Abstraction View is a graphical interface that shows the state space of each sequential component in a PEPA model. It provides a facility for labelling states (so that they can be referred to in CSL properties), and for specifying which states to aggregate.

Model Checking View

The Model Checking View is an interface for constructing, editing, and model checking CSL properties. The property editor provides a simple way to construct CSL formulae, by referencing the labels given to states in the abstraction view. It ensures that only syntactically well-formed CSL formulae can be constructed.

State Space View

The State Space View is linked to the active PEPA editor and provides a tabular representation of the state space of the underlying Markov chain. The table is populated automatically when the state space exploration is invoked from the corresponding top level menu item. A row represents a state of the Markov chain, each cell in the table showing the local state of a sequential component. The order in which sequential components are displayed corresponds to the order in which they are found in the cooperation set by depth-first visit of the cooperations binary tree. A further column displays the steady-state probability distribution if one is available. A toolbar menu item provides access to the user interface for managing state space filters. When a set of filter rules is activated, the excluded states are removed from the table. The probability mass of the states that match the filters is automatically computed and shown in the view. Filter rules are assigned names and made persistent across workspace sessions. From the toolbar the user can invoke a wizard dialogue box to export the transition system and one to import the steady-state probability distribution as computed by external tools. The view also has a Single-step Debugger, a tool for navigating the transition system of the Markov chain. The debugger can be opened from any state of the chain and its layout is as follows. In an external window are displayed the state description of the current state and two tables. The tables show the set of states for which there is a transition to or from the current state. The tables are laid out similarly to the views main table. In addition, the action types that label a transition are shown in a further column. The user can navigate backwards and forwards by selecting any of the states listed.

Performance Evaluation View and Graph View

Performance Evaluation View and Graph View A wizard dialogue box accessible from the top-level menu bar guides the user through the process of performing steady-state analysis on the Markov chain. The user can choose between an array of iterative solvers and tune their parameters as needed. Performance metrics are calculated automatically and displayed in the Performance Evaluation View. It has three tabs showing the

results of the aforementioned reward structures (throughput, utilisation, and population levels). Throughput and population levels are arranged in a tabular fashion, whereas utilisation is shown in a two-level tree. Each top-level node corresponds to a sequential component and its children are its local states. The Performance Evaluation View can feed input to the Graph View, a general-purpose view available in the plug-in for visualising charts. Throughputs and population levels are shown as bar charts and a top-level node of the utilisation tree is shown as a pie chart. As with any kind of graph displayed in the view, a number of converting options is available. The graph can be exported to PDF or SVG and the underlying data can be extracted into a comma separated value text file.

Experimenting with Markovian Analysis

An important stage in performance modelling is sensitivity analysis, i.e. the study of the impact that certain parameters have on the performance of the system. A wizard dialogue box is available in the plug-in to assist the user with the set-up of sensitivity analysis experiments over the models. The parameters that can be subjected to this analysis are the rate definitions and number of replications of the array of processes in the system equation. The performance metrics that can be analysed are throughput, utilisation, or population levels. If the model has filter rules defined, the probability mass of the set of filtered states can be used as a performance index as well. The tool allows the set-up of multiple experiments of two kinds: one-dimensional (performance metric vs. one parameter) or two-dimensional (performance metric vs. two parameters changed simultaneously). The results of the analysis are shown in the Graph View as line charts. For example, a parameter that may have an important impact on the performance of the system is the reset delay of the CPU.

Time Series Analysis

When performing a time-series analysis there are three basic steps to complete; component selection, solver selection and solver parameterization, all of which are handled by the time-series analysis wizard. Rather than simply observing all components, the wizard allows the modeller to select only those components that are of interest. This becomes more pertinent as either the number components in the system or number of observed time points increase - one limitation of the current time-series solvers is that all data is held in memory, and only written out to disk when exporting from the graph view. Solver selection and parameterization are self-explanatory, with the list of visible parameters being dynamically linked to the currently selected solver. In keeping with the rest of the UI, the selections across all three steps are persistent across invocations. Likewise, each unique parameter is stored only once, meaning parameters such as start and stop times are persistent over all solvers. Lastly, the parameters, including selected solver, are attached to the results in the graph view for future reference. Currently this meta data can only be seen when the data is exported. The last feature of the wizard is the ability to export the model in alternative formats, such as Matlab.

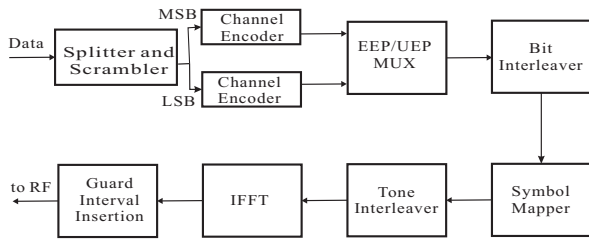


Fig. 1. The block diagram of the transmitter

V. PEPA REPRESENTATION

The mmWave PHY operates within the 57.24-65.88 GHz band as allocated by the regulatory agencies worldwide, and the spectrum is then equally divided into four channels. This high spectrum leads to dense frequency reuse, smaller sizes of radio frequency (RF) components, high antenna gain and secure data transmission. However, the high attenuation resulted by oxygen absorption, path loss and multi-path effects make the high data rate transmission difficult to deploy. In baseband, modulation methods are of critical challenge for mmWave communications. The PHY layer of both the HSI and AV modes are very similar and are based on the use of OFDM.

Figure 1 describes the block diagram of the transmitter for the IEEE 802.15.3c WPANs. Data are firstly split into upper and lower branches. The scrambled data are encoded with an LDPC encoder in the HSI mode, whereas for the AV mode, a Reed-Solomon (RS) code and a convolutional encoder are implemented. For the unequal error protection (UEP) modulation and coding schemes (MCSs), different coding rates are applied to the most significant bits (MSBs) and least significant bits (LSBs). The binary serial input data is then mapped to data symbols according to the modulation schemes. A normalization factor is multiplied to each modulation scheme in order to achieve the same average power. Overall the equal error protection (EEP) modulation dependent parameters and the data rates. A tone interleaver is applied before the modulated data are sent to the OFDM modulator. 512 sized IFFT is implemented to form one OFDM symbol, and 336 out of 512 subcarriers are data carriers.

$$Encoder_0 := \langle listen, \lambda_0 \rangle .Scrambler_0 \xrightarrow{L_0} \langle get, \lambda_0 \rangle .Channel - Encoder_0 ;$$

$$EEP_0 := \langle listen, \lambda_0 \rangle .EEP_1 \xrightarrow{L_0} \langle get, \lambda_0 \rangle .Bit - Interleaver_0 ;$$

$$Interleaver_0 := \langle listen, \lambda_0 \rangle .Symbol - Mapper_0 \xrightarrow{L_0} \langle get, \lambda_0 \rangle .Tone - Interleaver_0 ;$$

$$OFDM - Modulator_0 := \langle listen, \lambda_0 \rangle .IFFT_0 \xrightarrow{L_0} \langle get, \lambda_0 \rangle .Interval - Insertion_0 ;$$

PHY Layer equation defines how the components interact with each other. According to the working cycle and the definitions of model's components we give before, the PHY Layer equation is show below:

$$PHY := Encoder_0 \langle \lambda_1 \rangle EEP_0 \langle \lambda_2 \rangle Interleaver_0 \langle \lambda_3 \rangle OFDM - Modulator_0$$

A frame header is added to the resulting payload to convey information in the PHY and the Medium Access Control

(MAC) Layer headers necessary for a successful decoding of the frame. A PHY preamble is added prior to the frame header to aid receiver algorithms related to frame detection, frequency recovery, frame synchronization, and channel estimation. The format of a PHY frame includes PHY preamble, frame header and payload.

In IEEE 802.15.3c, a hybrid multiple access of contention-based CSMA/CA (carrier sense multiple access with collision avoidance) and contention-free TDMA (time division multiple access) is used. The CSMA/CA is mainly used for control signal transmission, while the TDMA is used for high-speed data transmission. This hybrid multiple access can reduce the data transmission collisions, and also maximize throughput by applying an optimum access time. The MAC layer throughput is determined by the amount of information bits exchanged between the transceiver MAC, and the duration needed for successfully delivering the information. Sources of overhead include gap time, preamble, header fields for the PHY and MAC layers, and ACK frames. The length of the ACK frames depends on the type of ACK, and there are five types of ACK defined for transmitting data frames in the piconet: no ACK (no-ACK), immediate ACK (Imm-ACK), delayed ACK (Dly-ACK), implied ACK (Imp-ACK), and block ACK (Blk-ACK).

$$Interface_0 := PHY \xrightarrow{L_0} MAC$$

$$MAC_0 := \langle Type - ACK, \lambda_0 \rangle .MAC_0$$

The overall system becomes *Interface* and *User* :

$$User_0 := Interface_0 \xrightarrow{L_0} User_0$$

$$User_n := User_0 \langle \lambda_1 \rangle User_1 \langle \lambda_2 \rangle User_2 \langle \lambda_3 \rangle \dots$$

VI. PERFORMANCE EVALUATION

A. State Space

According to the actions of each action and interactions among them, we can solve out the possible states. And according to the parameters setting of each action, we can derive a corresponding continuous time Markov chain (CTMC) of this model, which allow us to solve out each state's steady-state probability. The state space and steady state probability of this PEPA model is shown in Table I.

TABLE I
STATE SPACE AND STEADY-STATE PROBABILITY

No.	State	Steady-state probability
1	(1,1,1,1,1)	0.0749611139221529
2	(1,2,1,1,1)	0.05996889113772232
3	(1,3,2,1,1)	0.09994815189620386
4	(1,3,3,1,1)	2.9984445568861153E-4
5	(1,3,4,1,1)	0.09944841113672284
6	(1,5,1,1,1)	3.12337974675637E-4
7	(2,3,5,1,1)	0.044751785011525276
8	(2,3,6,1,1)	0.06961388779570597
9	(2,4,1,1,1)	0.12431051392090355
10	(2,3,1,2,1)	0.2088416633871179
11	(2,3,1,1,2)	0.08701735974463247
12	(2,3,1,1,3)	0.13052603961694872

The sets III the column state stand for the whole states of model, for example the set (2, 3, 1, 2, 1) represents the state (*PHY*, *Encoder*, *EEP*, *Interleaver*, *OFDM - Modulator*). However, the probability distribution of steady state is often

not the ultimate goal of performance analysis. Sometimes the designers are more concerned about the throughput, response time or utilization of the systems. In the following sections, we use the tool PEPE plug-in and Imperial PEPA Compiler (ipc) to evaluate the model's performance metrics of those characters.

B. Throughput Analysis

The study of how changes in performance depend on changes in parameter mode values is known as sensitivity analysis. We can vary some parameter's value a little, and see its influence degree to the model's performance, for example, the throughput or response time. Throughput is an action-related metric showing the rate at which an action is performed at steady-state. In other words, the throughput represents the average number of the activities completed by the system during one unit time.

From Figure 2, it can be observed that the impact of the number of devices on the throughput of transmit is more sensitive than the SC Mode. If we could make some efforts to optimize the cache, and raise the HSI Mode form 0.3 to 0.7 or even more high value, the throughput of transmit could greatly improved.

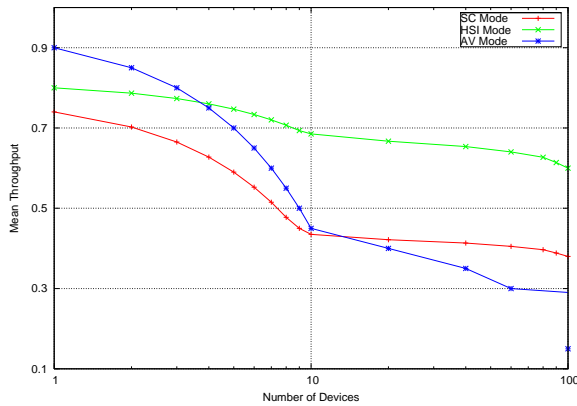


Fig. 2. Throughput versus Number of Devices

C. Response Time Analysis

Form the perspective of the WPAN system, the response time is the interval between the receiving of a request from the client and the transmission of the feedback content to the client. It is an important index of the system performance. The response time of WPAN system is relative to a lot of factors, for example, the configuration of system, the capability of components, the interaction processes among components, the health of the channel, etc. Figure 3 shows the cumulative distribution function of the response time between request and transmit actions. From the figures, it is clearly that when the possibility of hitting the cache parameter mode up from 0.01 to 0.8, the more possibility the response time would finally be a lower value, which is coincident with the result of throughput analysis we have got before.

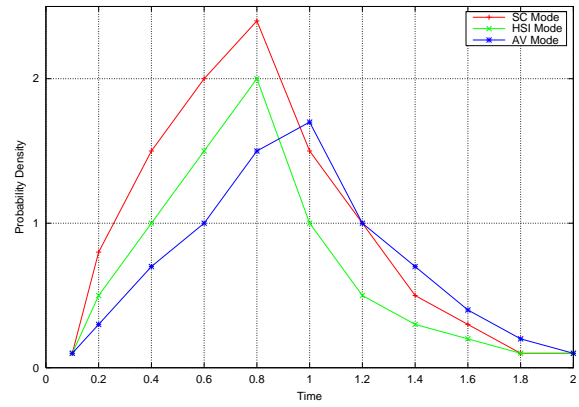


Fig. 3. Throughput versus Number of Devices

VII. CONCLUSION

In this paper, we have presented a detailed study of the IEEE 802.15.3c standard. The system throughput was studied by simulating both the SC, HSI and AV modes over a 60 GHz typical channel model. The link adaptation mechanism was described and the link throughput results were presented. The achievable number of devices was also investigated. The theoretical MAC throughput for different frame sizes and ACKs was calculated. The maximum achievable MAC throughput also relies on the link quality conditions. A typical PWNs system and the interactions within it, we have investigated it using the highlevel modeling formalism PEPA. This allows early analysis of potential designs and configuration to assess its performance measure. The system considered is simple, but this has allowed us to have a new idea about evaluating the performance of the way system in its design phase. Moreover, the method we used is more convenience, flexible, and lower cost than the former simulation method using special hardware and software tools. For example, when a new part is added into the system, designers just need specify a new component to the system model and express it using PEPA language, enabling designers to evaluate its impact to the system's performance. But the size of the state space of the underlying Markov chain would increase sharply with the increasing of components within system, which may lead to the problem of the state space explosion and cannot be computed easily. We can use two ways to deal with this problem at present, namely, aggregation and ordinary differential equations (ODEs), details can refer to [4, 5].

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Wireless Harness Inside ICT Equipments

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Abstract—We have been investigating point-to-multipoint wireless communication suitable for the use inside Information and Communication Technology (ICT) equipments to accommodate demands for weight saving, environmental lifecycle CO2 reduction and improvement of assembly/maintenance efficiency by means of replacing communication wire harnesses with wireless technology, that is wireless harness. Through the radio propagation measurements inside four equipments of automatic teller machine (ATM), ticket vendor, vending machine, and printer, a consistent specification applicable to them has been determined. Based on this specification, a test wireless system has been developed. It showed a good performance even inside the ATM that has the most lossy environment among the four equipments we tested.

Keyword—2.4 GHz ISM band, ICT equipment, radio communication equipment, radio propagation, wireless harness

I. INTRODUCTION

ONE of recent trends in wireless technology is machine-to-machine communication (M2M) using short range devices. As an expansive application of M2M, wireless communication inside machines has been recently receiving much attention aiming for the improvement of assembly/maintenance and weight savings. Several works have focused on these benefits of replacing wire harnesses with wireless communication, that is wireless harness, and reported

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its potential applicability in various vehicles and equipments such as automotive [1], [2], aircraft [3], spacecraft [4], [5], personal computers [6], and so on, through fundamental radio propagation measurements and feasibility tests.

Such utility of wireless harness also seems effective as a green technology to reduce CO2 emissions of machines. The reduction of CO2 emission is a big issue regarding with the global warming and has been challenged at all the sectors and various scenes in Japan. In accordance with these movements we have been studying the application of wireless harness to Information and Communication Technology (ICT) equipments that have a considerable amount of wire harnesses inside them. In addition, our study also covers the clarification of how effective the wireless harness of ICT equipments is on the reduction of CO2 emission. As a method to estimate the CO2 emission, we here employ a lifecycle assessment methodology that converts both the consumption of resources and energy into the amount of CO2 emissions during the whole lifecycle of the equipment. In our study, we have been focusing on the wireless harness of mechatronics ICT equipments. We have reported a fundamental study on measurements and modeling of radio propagation in four mechatronics ICT equipments; automatic teller machine (ATM), ticket vendor, vending machine, and printer [7], [8].

In this paper, we first show briefly the concept of the wireless harness of the mechatronics ICT equipments and review the radio propagation characteristics inside the above four equipments. Secondly, we show our dedicated wireless communication test system for mechatronics ICT equipments and discuss its performances inside the mechatronics ICT equipment. In order to understand an effect of the wireless harness on the reduction of CO2 emission, a trial estimation of CO2 emissions related to wire and wireless harness in the case of ATM is also presented.

II. CONCEPT OF WIRELESS HARNESS

Figs. 1(a) and (b) show the conceptual picture of the wire harness and the wireless harness communication inside the ICT

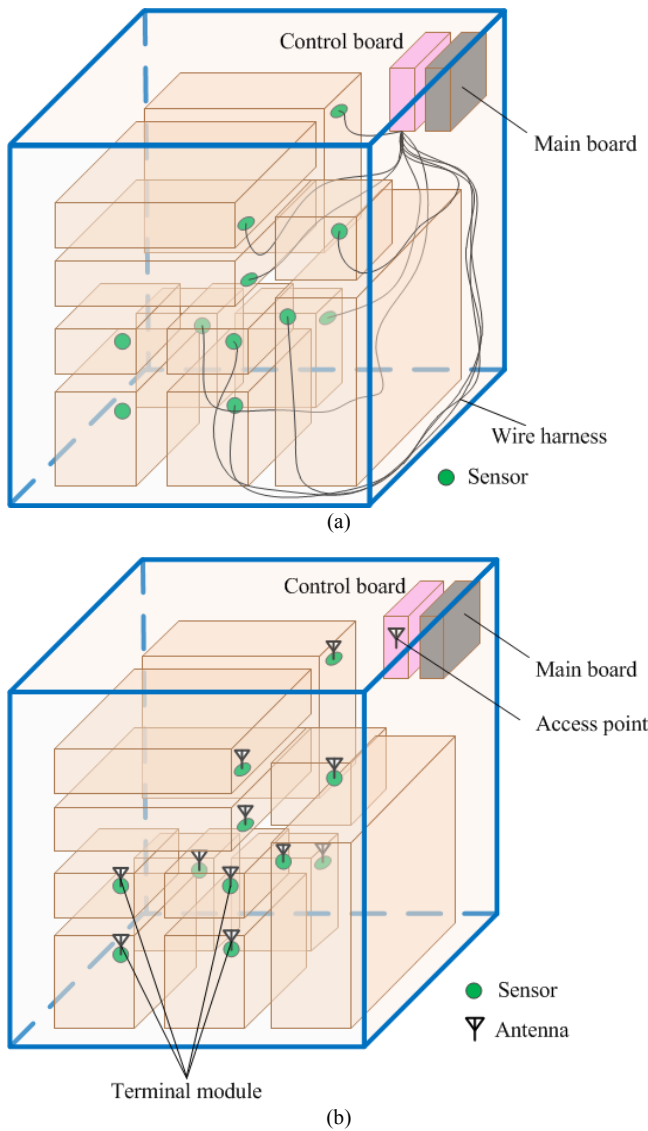


Fig. 1. Conceptual pictures of wire harness and wireless harness communication inside ICT equipment. (a) Wire harness communication and (b) wireless harness communication.

equipment, respectively. The ICT equipment, especially mechatronics ICT equipment, has a lot of sensors inside itself so as to monitor mechanical states in various positions such as transfer tracks and stockers in real time. As shown in Fig. 1(a), all these sensors are connected to a control board with wire harnesses in the present equipment. For example, ATM has about 200 sensors for monitoring and the total weight of the harnesses connecting sensors to control boards and a main board goes up to more than a couple of tens kilograms. Since the internal structure of ATM is so complicated and densely packed, the harnesses are swirled along with the frames and modules inside the chassis, resulting much longer than the straight-line distance. This increases technical difficulties in the assembly/maintenance processes. As shown in Fig. 1(b), the wire harnesses communication between sensors and the control board is replaced with wireless communication between

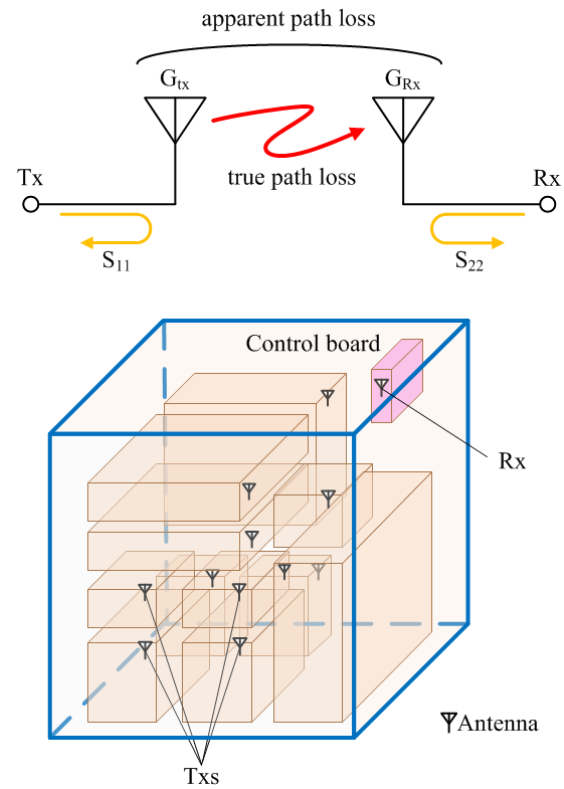


Fig. 2. Setup for measurements of the propagation loss and delay inside ICT equipment.

transmit antennas of terminal modules connected to sensors and a receive antenna of the access point on the control board. The application of the wireless harness into mechatronics equipments is very effective in assembly/maintenance load reduction as well as weight saving. As a whole, these must contribute to the reduction of the lifecycle CO2 emissions.

III. RADIO PROPAGATION INSIDE TESTED EQUIPMENT

The radio propagation environment inside densely packed mechatronics ICT equipments is significantly different from conventional outdoor and indoor ones. Through the challenge to apply wireless harness to mechatronics ICT equipments, we found out that the radio channel inside the equipment closely depends on its internal structure more than we expected. In order to understand the radio propagation characteristics inside such equipments, we measured propagation losses and delays inside four mechatronics ICT equipments [7], [8]. Now we show the typical examples of those measurement results.

The measurement setup for the radio propagation is shown in Fig. 2 Both transmit (Tx) antenna and receive (Rx) antenna are commercial 2.4GHz chip antennas (TAIYO YUDEN AH-316M245001) or ultra wide band (UWB) antennas (TAIYO YUDEN AH-086M555003). Tx antennas are placed at various positions near the sensor positions and the Rx one is fixed near the control board. The number of the measured Rx

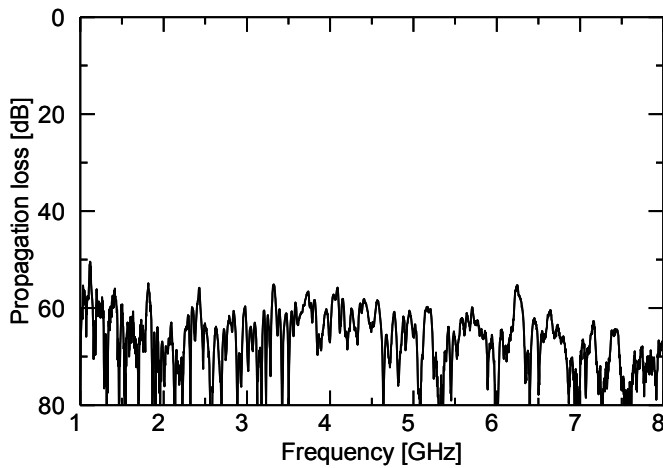


Fig. 3. Measured effective propagation loss in ATM. Tx antenna is located on NLOS from Rx antenna.

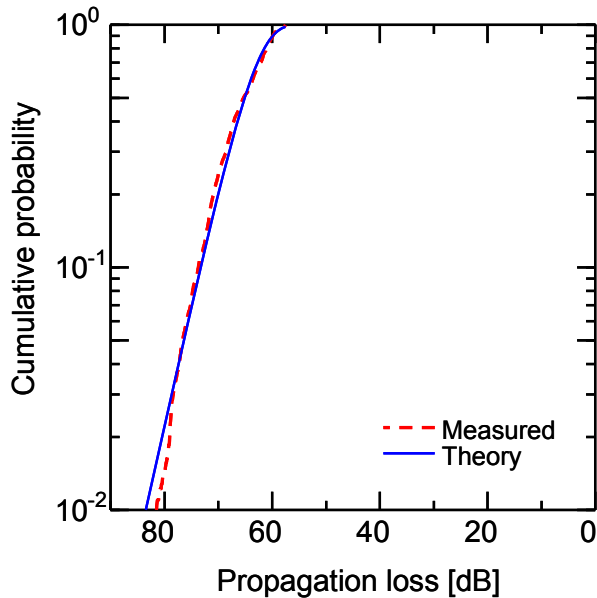


Fig. 4. Cumulative probability of measured effective propagation losses from 2.2 to 2.6 GHz in ATM. Tx antenna is located on NLOS from Rx antenna.

positions is about 40 to 70. The S-parameters of two ports are measured by a vector network analyzer (VNA). The frequency range is set from 1 to 8 GHz.

A. Frequency Characteristics of Propagation Loss

Fig. 3 shows an example of measurement results of the effective propagation loss in ATM as a function of the frequency. In Fig. 3, the Tx antenna is located on a non-line-of-sight (NLOS) from the Rx antenna. The effective propagation loss PL_{dB} in decibels is defined by

$$PL_{\text{dB}} = -P_{\text{Rx}} + L_{\text{Tx,ref}} + L_{\text{Rx,ref}} \quad (1)$$

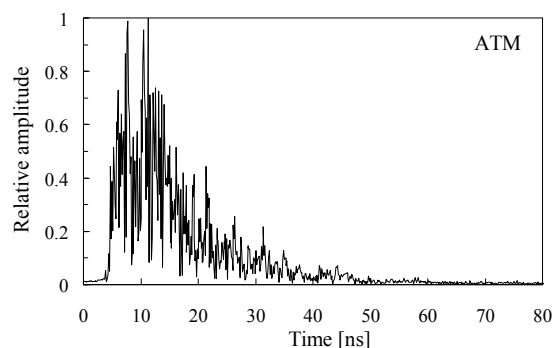
where P_{Rx} is the received signal power in decibels and $L_{\text{Tx,ref}}$ and $L_{\text{Rx,ref}}$ are the mismatch losses of Tx antenna and Rx one in decibels, respectively. The gain and the reflection characteristics of the antenna may be changed when the antenna is located near metallic or dielectric components. The gains of antenna are involved in the effective propagation loss. This is because it is difficult to remove the effective gains from the measured data at each measurement point. The reflection characteristics of the antennas are de-embedded from P_{Rx} as shown in (1). As seen in Fig. 3, a lot of deep nulls of effective propagation loss are observed in the measured frequency range. Frequencies and depths of these nulls depend on and are sensitive to the position of the antennas.

The cumulative distribution function of effective propagation losses from 2.2 GHz to 2.6 GHz in ATM is shown in Fig. 4. In Fig. 4, the Tx antenna is located on a NLOS from the Rx antenna. The theoretical curve is the Rayleigh probability distribution. A good agreement between the measurement and theory is observed.

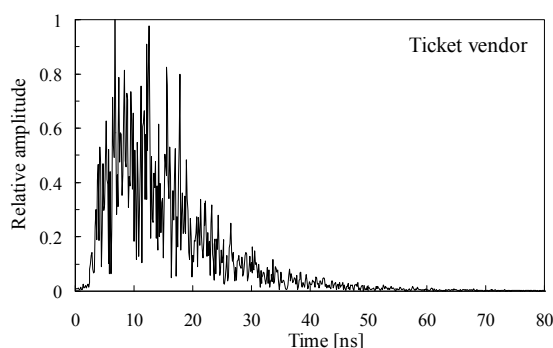
Such measured characteristics show that the inside of the ATM are typical multipath-rich environments and the propagation loss distribution for NLOS obeys the Rayleigh model. We also confirmed that these propagation loss characteristics are almost same in ticket vendor and vending machine. Though we omit the detailed measurement results here, in the case of printer, the propagation loss distribution for NLOS obeys the Nakagami-Rice model because the printer has a fewer components causing the shading and reflection of the radio wave inside itself than the other equipments. This indicates that the multipath waves are not always the dominant components inside equipment with few components causing the shading of the radio wave and the stationary wave with larger amplitude to be the dominant component exists among the multipath waves.

B. Propagation Delay

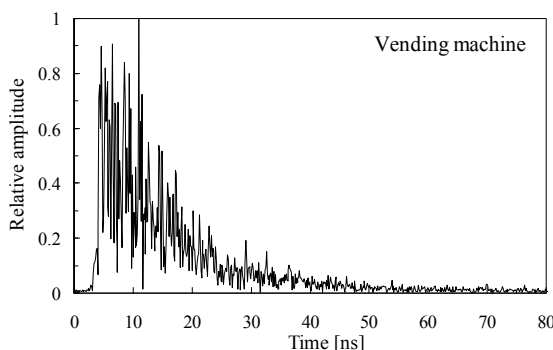
Fig. 5 shows examples of the measurement results of the propagation delay inside four equipments. As shown in Fig. 5, the complex multipath propagations are observed because the insides of these equipments are very complicated and multipath-rich environment as mentioned before. The observed propagation delays are less than 50 ns in various positions in ATM, ticket vendor, and vending machine. Their chassis are mainly made of metal. However, they have slits and windows, so that the radio wave easily dissipates from the inside. This helps the propagation delay be in the same range of that observed in a chassis of personal computer [6]. On the other hand, the printer that has a plastic chassis shows a shorter propagation delay, and which is less than 30 ns. This indicates the dissipation of the radio wave for printer is larger than the other equipment. The measurement results and the models of radio propagation in these equipments are summarized in Table I. Based on these observations we decided to treat ATM as a representative of mechatronics ICT equipment while considering broader applicability to other equipments.



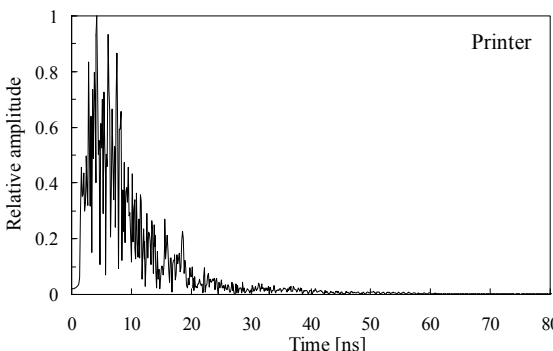
(a)



(b)



(c)



(d)

Fig. 5. Measured propagation delay inside the four ICT equipments: (a) ATM, (b) ticket vendor, (c) vending machine, and (d) printer.

 TABLE I
 MEASUREMENT RESULTS AND MODELS OF RADIO PROPAGATION IN FOUR ICT EQUIPMENT

Equipment	ATM	Ticket Vendor
Size (cm) (width \times length \times height)	57 \times 104 \times 120	50 \times 90 \times 150
Chassis	Metal	Metal
Propagation loss for distance $<$ 1 m	20 – 70 dB	20 – 50 dB
Propagation delay	\leq 50 ns	\leq 50 ns
Propagation loss model at far positions	Rayleigh	Rayleigh

Equipment	Vending machine	Printer
Size (cm) (width \times length \times height)	70 \times 70 \times 180	48 \times 48 \times 55
Chassis	Metal	Plastics
Propagation loss for distance $<$ 1 m	20 – 60 dB	20 – 60 dB
Propagation delay	\leq 50 ns	\leq 30 ns
Propagation loss model at far positions	Rayleigh	Nakagami-Rice

IV. SYSTEM DESIGN AND SPECIFICATIONS

Although there were a couple of candidates among commercialized products such as Bluetooth [9], ZigBee [10], and UWB [11] systems and actually some of them were tested inside our equipments at an early stage of our work [12], we decided to make a custom system based on a commercialized radio frequency integrated circuit (RF-IC) running at 2.4 GHz Industry, Scientific, and Medical (ISM) band. Some of the reasons for this are to satisfy our primary requirements that the system shall simultaneously collect status data from as many as 200 sensor transmitters, each of which runs with 1 kHz sensing frequency and with a system latency of 1 ms. These requirements are mainly derived from a current wired system of ATM as a case reference. The existing technologies such as Bluetooth and ZigBee seemed hardly applicable to meet with these requirements without deep level modification. Though UWB is a fascinating high-speed technology, we have to consider power consumption of sensor transmitters and the radio wave regulation of Japan that limits UWB to indoor use at present. Thus we decided to design a point-to-multipoint custom system. Table II summarizes our system specifications.

V. ANTENNA

Since a lot of metals and dielectric components are closely arranged inside mechatronics ICT equipment, extra free spaces available for additional placement of wireless modules are not so large. The distances between adjacent components look 2 to 5 cm at best. In some places aerial slits are as narrow as less than 1 cm. Antennas on the wireless modules inside equipment,

TABLE II
SYSTEM SPECIFICATION

Num. of sensor modules (transmitters)	up to 200
Sensor data	0/1 (bit datum)
Sensing frequency at each sensor	1 kHz
Radio communication frequency	2.4 GHz ISM band
Modulation	GFSK
Access protocol	FTDMA
Communication speed	1 Mbps

therefore, have to be inevitably placed close to the components. In order to know how the antenna performance is affected by adjacent metals, we first measured variations of the reflection coefficient (S11) by employing a setup shown in Fig. 6. An antenna under test was placed on the surface of one aluminum plate and the other aluminum plate was brought to closer to the antenna. Fig. 7 shows the measured reflection coefficient of a commercial 2.4 GHz chip antenna with various separations between two aluminium plates. As shown in Fig. 7, the reflection characteristic of the chip antenna easily varies and degrades when the aluminum plate was closely placed. Compared to the free space condition, the reflection coefficient at 2.45 GHz got worse to -10 dB at 20 - 30 mm and -5 dB at 15 mm. Though these results are specific examples of the antenna performance degradations, we also observed almost same antenna performance degradations inside the mechatronics ICT equipments.

In order to obtain stable antenna performance inside mechatronics ICT equipments, we designed a dedicated antenna to have better performance when a metal plate exists at around 20 mm and to be insensitive to the environmental change. Fig. 8 shows a picture and a configuration of the developed antenna. We adopt the shorted microstrip antenna (shorted MSA) in our wireless harness communication system because it may be suitable for use in a narrow space such as the inside of mechatronics ICT equipment because of its low-profile structure. Moreover, shorted MSA has a ground plane on its back face and is expected to be less sensitive to the proximity of the metals to the ground plane side. The dimensions of the antenna are 25 mm × 30 mm × 2.5 mm. The wide and depth are same as the board size of terminal module described later. The height of the antenna is about 1/50 of the wavelength at the center frequency 2.44 GHz. In order to enhance the bandwidth of the antenna, we use the double folded L-probe proximity feeding structure [13] as shown in Fig. 8(b).

Fig. 9 shows the measured reflection coefficient of a developed antenna with various separations between two aluminium plates. As shown in Fig. 9, the antenna exhibited much more stable characteristics than the conventional one shown in Fig. 7. The averaged reflection coefficient keeps better than -11 dB from the free space to the distance of 15 mm in the range of 2.4 to 2.5 GHz.

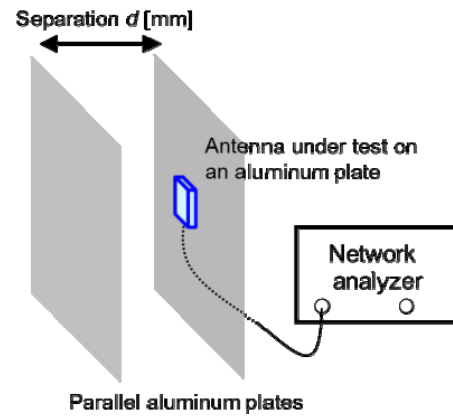


Fig. 6. Measurement setup of antenna characteristics at close positions to metals.

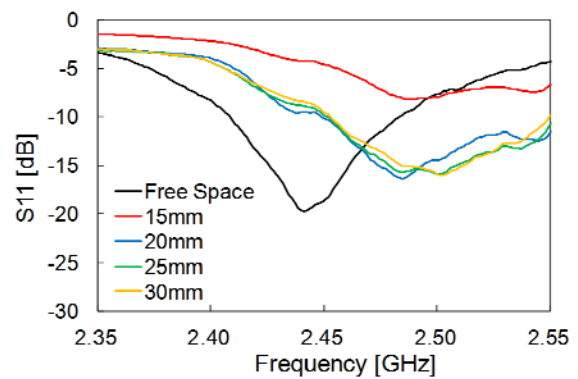


Fig. 7. Measured reflection coefficient of a commercial 2.4 GHz chip antenna.

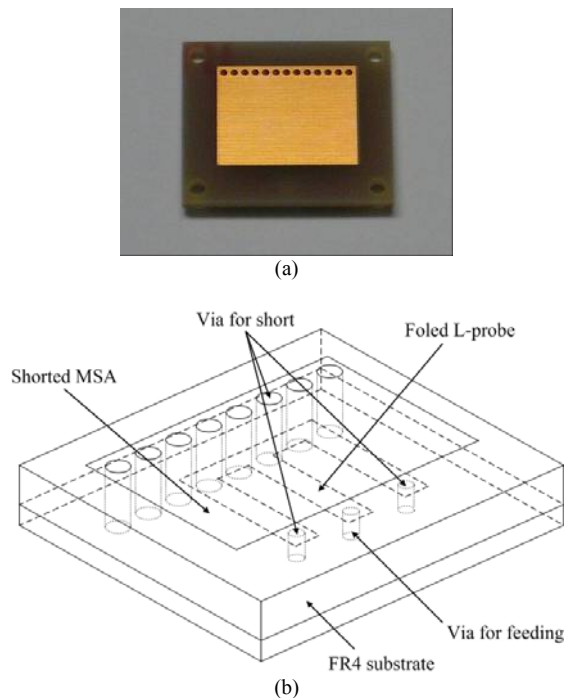


Fig. 8. Configuration of the developed antenna. (a) Photo. (b) Configuration.

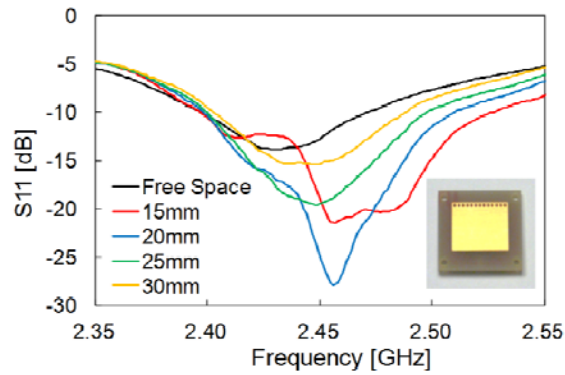


Fig. 9. Measured reflection coefficient of a developed antenna with various separations between parallel aluminium plates.

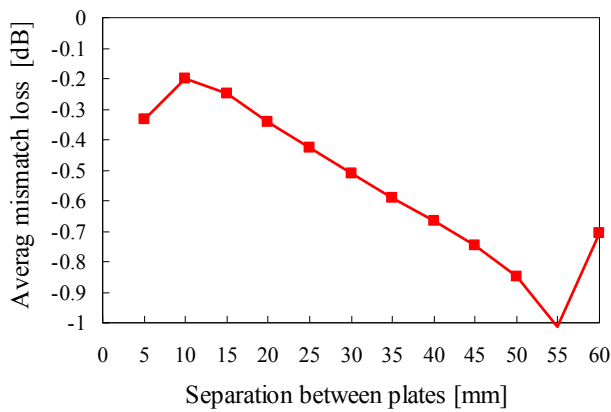


Fig. 10. Measured average mismatch loss of a developed antenna.

Fig. 10 shows the measured average mismatch loss (averaged between 2.4 and 2.5 GHz) of our developed antenna. As seen in Fig. 10, the average mismatch loss becomes the minimum at the separation $d = 10$ mm and is less than -0.4 dB for $d < 20$ mm. As can be seen from these results, our developed antenna has a stable and good antenna performance between the metallic plates. Though these measurement results only show the antenna performances in the ideal situation such as in the parallel metallic plate, we observed our developed antenna also shows a good performance in the mechatronics ICT equipments.

VI. WIRELESS COMMUNICATION SYSTEM

A. Wireless Modules

To match the specifications listed in Table II, we made a custom wireless module based on a commercially-available RF-IC produced by Nordic Semiconductor. Fig. 11 shows a terminal module coupled with an antenna developed. It has two connector ports to sensors and a board size of $25 \text{ mm} \times 30 \text{ mm}$. In this module custom protocols described next are embedded. The combined wireless module shown in Fig. 11 is a kind of functional test version.

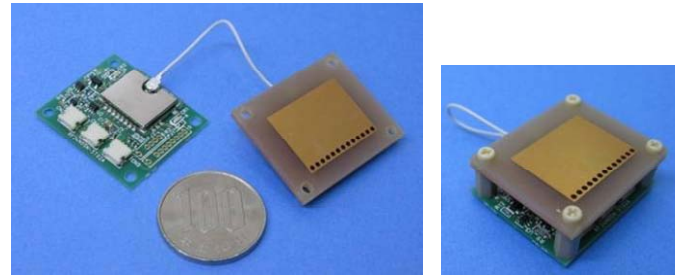


Fig. 11. A pair of a wireless module and an antenna. The right photo shows an assembled state.

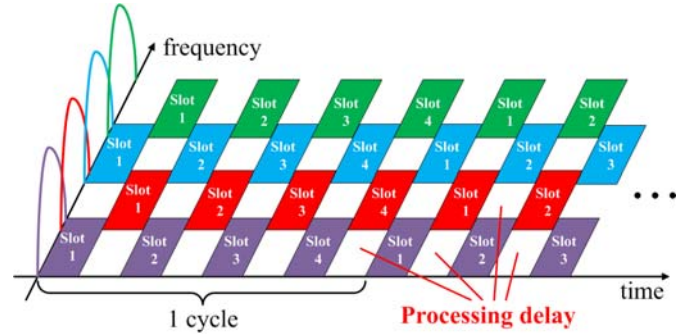


Fig. 12. FTDMA protocol sequence using four slots at each frequency with checkerboard packet configuration.

B. Protocols

Fig. 12 shows a frequency and time division multiple access (FTDMA) protocol sequence which is implemented on the RF-IC as an access protocol inside mechatronics ICT equipments. The system is designed to utilize 73 frequency channels with 1 MHz bandwidth in the range of 2400 MHz to 2480 MHz and each channel has four time slots. A guard time is set for compensating the processing delay of RF-IC and guard frequency band is prepared to avoid the interference from adjacent frequency channels. Therefore, the guard time is allocated to the transmission time of both the adjacent frequency channels in order to use frequency band efficiently.

The allocation of frequency to each terminal module is pre-processed at initial setting to avoid severe multi-path interference and functionalize frequency diversity effect. The allocation of frequency is decided based on the following evaluation value V of n th terminal module at m th frequency channel:

$$V(n, m) = \frac{-\log_{10}(PER(n, m))}{\frac{1}{N_{ch}} \sum_{k=1}^{N_{ch}} [-\log_{10}(PER(n, k))]} \quad (2)$$

where N_{ch} is the total number of frequency channels and $PER(n, m)$ is the packet error rate (PER) of the n th terminal module at m th frequency channel. The denominator of (2) is PER characteristics averaged over all frequency channels and

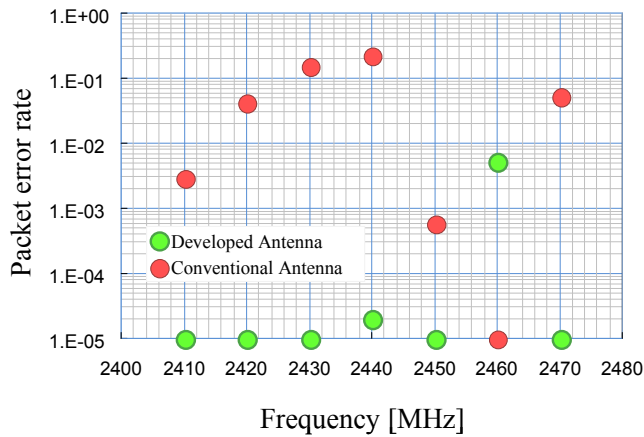


Fig. 13. Comparison of packet error rates between our developed antenna and the conventional antenna.

becomes smaller with the worse communication quality at all frequency channels. On the other hand, the numerator of (2) is PER characteristics at a certain frequency channel. Therefore, higher V is obtained when the communication quality is bad over all frequency channels and comparatively good at a certain frequency channel. The frequency channels are allocated according to the magnitude of V , in order from the terminal module with highest evaluation value V . Currently we utilized a pre-installed packet format for communication, and thus put a couple of sensor data into one payload to transmit. Though the packet has a length of 72 bits, that is too long for datum length of each sensor and even for a couple of sensors, the total data volume of 200 sensors with 1 kHz repetition can be successfully transmitted to the access point (Rx) with using FTDMA, running at 1 Mbps in each channel.

C. Performance

Performances of our developed wireless module and antenna were measured in ATM. An access point was placed near the backside of the front panel, and the terminal module was placed close to the rear panel. The straight-line distance of them was more than 50 cm. The arrangement was where the propagation obeys Rayleigh distribution and the propagation loss was about 60 dB. Fig. 13 shows the measurement results of PER against 7 frequency channels from 2400 MHz to 2480 MHz. In Fig. 13, green and red dots mean performances of our developed antennas and conventional 2.4 GHz meander-line inverted-F antennas that the RF-IC supplier recommended, respectively. As shown in Fig. 13, PER with the developed antennas achieved 10⁻⁵ level in the wide range of channels. The degradation of PER at 2460 MHz seems to be due to the severe multi-path interference and a steep increase of propagation loss, which is sensitive to the position of the terminal module. As shown in Fig. 13, average to say, our developed antenna showed better performance in ICT equipment.

In our early measurement of bit error rates (BER) at various positions inside ATM, about 10% of the positions exhibited very lossy conditions probably due to the environmental reason

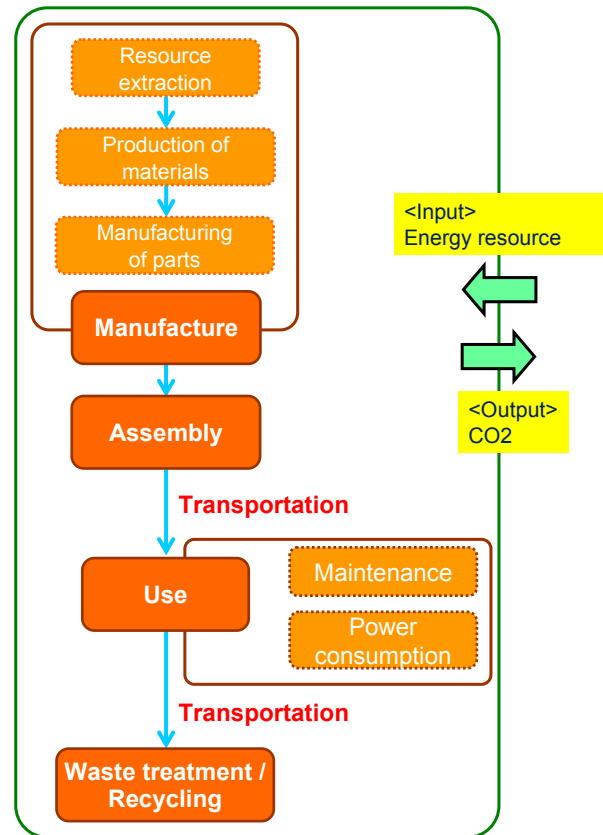


Fig. 14. Evaluation boundary of our case study on the trial estimation of CO2 emissions.

and multi-path interference and suggested difficulty to achieve BER being 10⁻⁶ level or better. Fig. 13 is only one example and we can also achieve BER < 10⁻⁶ (corresponding PER is about 8.1 × 10⁻⁵) at dozens of sensor positions we measured inside ATM by adopting our developed antenna and FTDMA based channel allocation.

VII. GREEN EFFECT

The benefit of the wireless harness in terms of lifecycle CO2 reduction has been estimated [14]. The difficulties in such estimation at an early stage of test development phase include the collection of appropriate primary units of elemental parts and the framework of evaluation.

Fig. 14 shows the evaluation boundary of our case study. The manufacture process includes the resource extraction, the production of materials, and manufacturing of parts (cables and connectors / wireless modules). The assembly process means assembling the equipment with wire harnesses or wireless modules. In the use process, power consumptions by wireless modules and by the movement of workers for maintenance are included. In the waste treatment and recycling process, shredding process of equipment is only evaluated. In our study, the transportation of products and wastes is only considered and that of resources, materials, and parts is neglected.

Table III summarizes the trial estimation of CO2 emissions

TABLE III
CALCULATED CO₂ EMISSION
(a) Wire harness. (b) Wireless harness. (Kg-CO₂/unit)

Lifecycle process	(a)	(b)
Manufacture of cables and connectors	288	0
Manufacture of wireless modules	0	145
Assembly	74	41
Transportation	69	54
Use	12	0
Waste treatment and recycling	3	2
Total	444	241

related to wire and wireless harness in the case of ATM. In the estimation of the wireless harness, CO₂ emissions are calculated in a case where the wireless harness is applied to the wire harness not only between sensors and the control board but also between the control board and the main board of ATM taking into account the future expansion of applicability of our wireless harness technology.

In the case of wire harness, the major process of the CO₂ emission is found to be the manufacture of cables and connectors. It occupies 65% in the total CO₂ emission. In the case of wireless harness, it is found that the manufacture of wireless modules process occupies 60% of the total CO₂ emission and the CO₂ emission of the use process, that is CO₂ emission due to the power consumption by wireless modules, is negligibly smaller than that of the other processes. This result indicates that the manufacture of cables and connectors and wireless modules are more important than other factors. Although the assembly, transportation, use and waste treatment and recycling processes have been addressed as distinct loads and speculated to have considerable CO₂ emissions, they occupies 35% to 40% of the total.

Though these estimated values seem to have considerable errors at current stage, the estimated amount of CO₂ reduction by replacing the harness with wireless harness becomes 203 kg CO₂ per a unit and is not negligible. This indicates the wireless harness almost certainly has a very good effect to the reduction of CO₂ emissions when it is applied to ICT equipments that have a lot of wire harnesses in them.

VIII. CONCLUSION

Based on the measurement results of radio propagation inside ICT equipments, we settled down a consistent specification to fit for use of sensor data acquisition, and built up a test system of point-to-multipoint wireless communication. The system runs with 73 channels using 2.4 GHz ISM band. It enables to connect 200 sensor-transmitter modules and retrieve sensor data with dedicated packet protocols. The test system exhibited good performance even inside ATM, the inside of which is the most severe environment for radio propagation among the equipments we tested. The application of wireless harness to ICT equipments seems to offer wider variety of merits such as weight saving, slim-design, abatement of

assembly/maintenance, and reduction of lifecycle CO₂ emission as a result.

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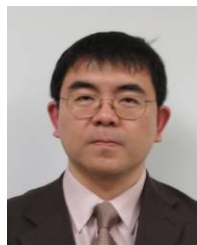
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Analysis of voice quality over infrastructured WLAN with Distribution System

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Abstract— This assignment presents a study about voice transmission in WLAN networks based on IP protocol (VoIP). The assignment presents an statistical analysis of the QOS (Quality of Service) metrics of these networks for VoIP transmission. We considered to make calls on a scenario where WDS (Wireless Distribution System) exists. The objective is to analyse the impact that the WDS may bring on in voice transmission. The results found are compared between the two environments and presented in tabular and graph form.

Index Terms—WLAN, VoIP, WDS

I. INTRODUCTION

The traffic generated by real time multimedia applications in mobile devices grows exponentially day-by-day on the internet. It is common to find such devices connected to the internet through WLAN, 3G, WiMAX networks among other wireless access technologies. With mobile users increasingly thirsty for content, connection speed and largely for the network availability anywhere using the available means on their devices, we observe one of the greatest challenges faced by the network managers, the service quality in WLAN networks.

According to jiwire [1] indicators the number of Wi-Fi hot-spots tripled around the world in four years. This raise is justified due to the popularization of the mobile devices like smartphones and tablets. The most part of these users, which corresponds to 55% of the mobile users surveyed seeks the wireless access as a way of fast connections with a minor cost per data traffic. The real time multimedia applications detached in [1] are the on demand video transmissions, and voice over IP (VoIP).

Attend this raising demand of applications is one of the

challenges faced by the managers, preserving the minimum quality of the services provided by these networks in any point of the network. The number of access points (AP) controlled can raise significantly according to the coverage area and the number of users to be integrated to these networks. One of the commonly used technologies to realize the WLAN networks distribution is the WDS (Wireless Distribution System). WDS allows the interconnection among Aps without cables, through the own AP's wireless interface. Such characteristic is extremely interesting when it is intended to expand the network to regions where the cabling is unable to reach. With WDS function active the AP starts to realize the function of repeater of the clients signal to the central AP connected to the main network (DS). Within this the WLAN signal coverage is expanded according to the installation of other Aps with WDS. In contrast one disadvantage is that the reduced bandwidth due to the sharing with the connected users and a little latency inserted on the network by WDS.

Real-time applications like VoIP have characteristics of delay intolerance, packet loss, lack of bandwidth, voice compression, therefore it is necessary the use of mechanisms to assure the Quality of Service (QoS). Many other aggravating already known can be detached when the use of VoIP is related with the transmission means, mainly when the used mean is the wireless pattern.

This assignment has as an objective analyse the impact of VoIP implementation in WLAN networks, with the use of WDS through call analysis. To reach the research's objective, It was necessary to create two WLAN environments. In both environments we executed VoIP calls and each collect was processed with the use of a packet analyser. Using statistic tools it was possible to obtain the QOS's metrics involved. The intention is to appreciate the impact caused by the use of VoIP applications in environments with WDS.

To evaluate such impacts we realized tests with the purpose of obtaining the QOS's metrics: delay, outflow, jitter and loss. From the obtained results, we expect to conclude that such metrics have different values in environments using WDS, what may compromise the quality of service. This assignment is organized as follows. In section 2 it is described the bibliographic study. In section 3 it is described the study's

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proposal and in section 4 it is described the used tools, the process of the environments's implementation, methodology and data analysis. In section 5 are exposed the results. In section 6 are presented the research's future assignments.

II. RELATED WORKS

Local wireless networks (WLAN) are a viable and economic alternative for the conventional networks based in cabling. The great number of mobile devices with wireless interface offered in the market grows each day, as well as its search due mainly to the drop of the prices of electronic components. Today it is possible to find many devices with wireless communication interface due to its setup facility, low costs of implementation and the mobility that this interface offers to the device.

WLANs provide the same basic functionalities of cabling networks (LAN), but combining mobility with access speed that results in the creation of new habits, relations and ways of working. A good example is on the major use of services that demand real time requirements like voice applications over IP and video on mobile devices. The use of multimedia services (voice and video) may demand resources reservations and availability to have a good functioning and provide a good use experience to the user. Initially WLAN networks, based on the 802.11 pattern were not projected for this kind of traffic. For the multimedia services to function properly, the associated use of the packets prioritization techniques may be necessary.

The pattern WLAN 802.11b and 802.11g can support theoretically 200 and 900 VoIP sessions respectively, but due to the inclusion of a great number of headers this number is reduced drastically to only a few sessions. The headers added to the payload consist in the real time protocols (RTP), UDP, IP and headers of the MAC layer 802.11. According to [2], the 802.11g pattern presents the best performance for the VoIP traffic in relation to the 802.11a and 802.11b patterns, in both types of CBR (Constant Bit Rate) and VBR (Variable Bit Rate) traffic. A comparative study was realized using the patterns 802.11a and 802.11g and 802.11b where it was illustrated the maximum number of sessions and broadcasting rates on the Nominal and Multiplex-Multicast (M-M), for both types of traffic CBR and VBR.

As an alternative to raise the number of supported sessions in WLAN networks, it was proposed the use of the M-M regime to send packets where the data load reduction was provided for the Multicast packet sending regime. In this mode the headers UDP, IP and RTP are compressed and rewritten in a mini-header and after this combined in a single packet Multiplex-Multicast, where right after it is sent through the WLAN to the IP Multicast address. Among the three patterns analysed in [2] the 802.11g had the best performance compared to the others, with VBR traffic and M-M regime, the difference among the others showed to be well significant in the number of VoIP sessions supported and in the bitrate reached. Using VBR traffic the flux rate is variable and exist the packet send economy with periods of silence, what ensure a better audio

quality transmitted.

Other important factor related in the use of WLAN networks can be described as an interference of many other networks very close, producing the interference among them. When there are many other WLAN networks in a small geographic area the number of supported sessions is reduced even more, reaching values between 1.63 and 10.34 sessions using only the GSM codec 6.10. According to [3] one of the main culprit by the reduction of the VoIP session numbers in areas with multiple WLAN networks is the mutual interference of CSMA (Carrier Sense Multiple Access). Many transmission sources using the same frequency or very close frequencies end up suffering interference into one another. This way the percentage of lost packets can raise what is not interesting to any intolerant to losses application, including VoIP.

To weaken the number of sessions it was proposed in [3] an admission call control based on a graphic model of conflicts, where it was possible to raise in 52% the number of VoIP sessions using the pattern 802.11b and 802.11g, what represented the number of 2.48 and 14.14 sessions. It was also proposed the use of three orthogonal channels to reduce the lateral interference, what raised the supported sessions capacity in the 802.11b and 802.11g patterns to 7.39 and 40,91. With the use of CoTDMA (coarse-grained time-division multiple-access) in a partnership with CSMA was possible to obtain an improvement of 35% in the used patterns, that resulted in 10 sessions to 802.11b and 58 sessions to 802.11g.

Other relevant factor to the VoIP is the voice quality transmission in IP networks evaluation. The evaluations can be done through subjective methods, where people do the listening evaluation, or in an objective form these based on mathematic models. In [4] it is referred the recommendation ITU-T P.800 as one of the methods and procedures used for this kind of evaluation. It consists basically in computing an average opinion of the listener in a scale from 1 to 5. This scale is known as MOS (Mean Opinion Score). The MOS scale is the following: 1 – for a horrible quality, 2 – for bad, 3 – for a reasonable, 4 – referring to a good quality, and 5 – for an excellent quality. In [5] it is presented many objective methods, with emphasis for the E-model presented as an effective method on the voice quality. The E-model is an evaluation model based on a concept where “psychological factors on a subjective scale are auditory”, that is factors gauged from the call quality loss may be computed generating a scalar model named R factor. The R factor scale has a variation from 0 to 100. The R factor [5] is calculated from the equation (1).

$$R = (Ro - Is) - Id - Ie + A \quad (1)$$

Ro is the noise signal relation; according to the recommendation the pattern value is 94.77. **Is** is the factor for the voice quantization, and its pattern value is 1.41. **Id** corresponds to the delay degradation. **Ie** represents the signal distortion caused by the codecs, loss and buffers. For the codec

G.722 used in this study we assumed the value of the recommendation like being 13. And finally *A* corresponds to the quantity of degradation that the user is willing to accept. In this study we assumed the value 10, that in the recommendation refers to the quality in celular networks with mobility. The articles and recommendations studied indicated alternatives to fix or improve the performance of the use of VoIP on WLAN networks. In this assignment, accordingly described previously it will be analysed the use of WDS as a way of WLAN network expansion, thus seeking to prove its performance in relation to the VoIP and the induced impact. All collected samples in this study were made in real environments, without the use of simulators. No QOS policy is implemented in both environments. As a method of the quality call's evaluation in this study will be used the E-model.

III. PROPOSAL

The objective of this study is to analyse from a statistic point of view the variables (random), latency, jitter, packet loss and the throughput measured in a non-intrusive way in WLAN networks making use of a VoIP application. We proposed also to realize an objective measurement according illustrated in picture 1 about the speaking quality, obtaining the prediction of the quality call based on the parameters of delay using the E-Model. In this study the evaluation will be realized through experiments in real environments, the first in a WLAN network without the use of WDS, and second in a WLAN network with WDS at the Federal Institute of Education, Science e Tecnology – IFTO.

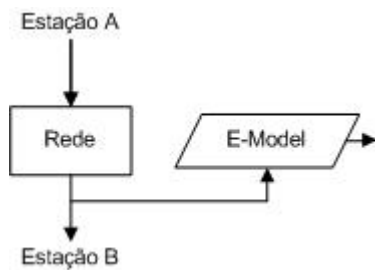


Fig. 1. Non-Intrusive Measurement Objective

The size of the collected sample in this environment will be realized per point, the size of the sample will be applied in both environments for statistic analysis purposes. Addressing the study of random variables, in these environments we adopt an average of the metrics found as a comparative value, because these values can be different according to the network demand, time, background traffic among other variables that may interfere in the result. A pre-sample will be processed in the second environment of this study with the objective to serve as initial parameter for the size of the sample in both environments, this way avoiding waste of resources and operating costs with unnecessary collection. Knowing that the second environment tends to be to most degraded considering

that the first does not exist the background traffic, that is, without any network use at the time of the VoIP calls, it will be realized a pre-sample with the objective of knowing the average values and average diversion pattern for each one of the analysed variables. From the calculation of the sample size (2) we seek to know an ideal sample size for both environments with 95% trustyworthy of finding the real average values for quality metrics of service in voice transmissions under IP networks.

With the sample size defined, with all the samples collected, processed and with its respective graphics we have the capacity to analyse the impact caused by the use of WDS in WLAN networks in VoIP transmissions. The metrics found will be analysed, compared and discussed, this way we intend to get to a conclusion of the benefits of the use or not of the WDS as a way of expansion of a WLAN network and mainly to point out the positive and negative points of the use of the technology.

A. Materials

The materials used in this study are the ones related on table I. The access points used were the 3COM 7760[11] model, referred now like WDS1 and WDS2. The operating system used on the stations was Ubuntu 10.10 32 bits [6] installed on the two laptops Asus Eee PC 1015PEM [7] referred now as station A and Station B. The multimedia applicative that allowed the accomplishment of the calls between stations A and B was the Jitsi [8]. The codec used in both environments was the G.722. In the analysis phase, it was used the statistic software R [9] to execute the calculations and the Gnuplot [10] to illustrate the results with graphics.

TABLE I
MATERIALS

	VERSION
<i>Computer</i>	Asus Eee PC 1015 PEM
<i>System Operational</i>	Ubuntu 10.10 Maverick Meerkat
<i>Softphone</i>	Jitsi 1.1
<i>PBX</i>	Askozia Embedded 2.0.4
<i>Codec</i>	G.722
<i>Sniffer</i>	Wireshark 1.8.0
<i>Statistical Software</i>	R-2.15.1
<i>Graphics</i>	Gnuplot 4.6.0
<i>Access Point</i>	3Com 7760 a/b/g PoE

On the PBX two SIP counts were added with identification 101@200.129.176.50 and 102@200.129.176.50 to configure on stations A and B. The packet analyser was installed on station B with the objective of realizing the capture in parallel to the call answering, accordingly illustrated in picture 1. The WLAN networks in both environments do not have any security key set. The distribution of the IP addresses to the stations was realized through DHCP protocol.

B. Environment 1

The first environment proposed was the scenario where the

WDS is not implemented. Picture 2 illustrates the environment created to collect the samples. The environment was configured in a typical form, being this a BSS (basic service set) composed by an access point pattern 802.11g connected directly through the port uplink to the PBX VoIP. The A and B stations were associated to this BSS to make use of the VoIP application.

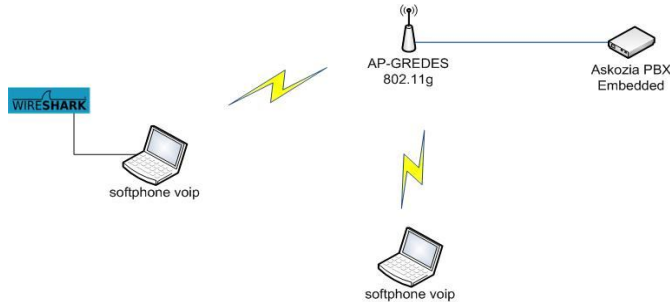


Fig. 2. Environment 1 without a WDS.

In this environment were realized calls between the two stations and captured the exchanged packets during the collected sample. The packets were saved in an archive of the own wireshark, where each file corresponds to a realized call. After collecting the files were exported to the CSV format (Comma-separated values). Right after the files were imported on the R software to realize the statistical analisys. The calculations that were realized are based in the QOS's metrics: latency, jitter, packet loss and outflow.

The stations remained without mobility in the moment of the realization of the calls. The distance between A station and the access point was about 4 meters and between B station it was 3 meters.

C. Environment 2

The second environment proposed was based in a WLAN network with WDS existing at IFTO. This environment is composed by two access points (AP) forming an ESS (Extended Service Set) connected through its wireless interfaces. Picture 3 illustrates this environment, as well as two stations that were configured to this network to make calls.

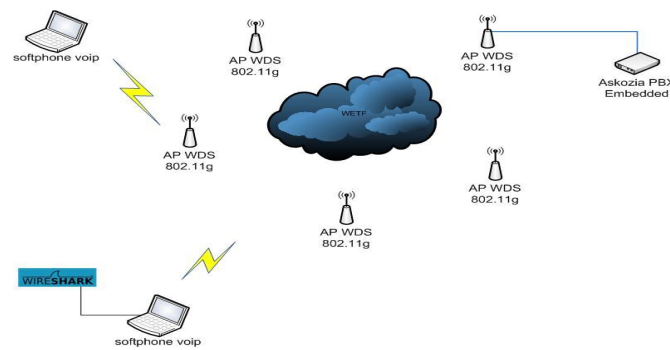


Fig. 3. Environment 2 with WDS.

The location of the stations in relation to the access points is defined on table II. The collection points were named with P1 for the collection point 1 and so on until the collection point P5.

Both access points were named in the image as WDS1 and WDS2. All the collections in this environment were realized in a space outdoors. On table II it is illustrated the distance in meters in relation to the access point at the moment of collection and the number of necessary jumps until DS (distributed system).

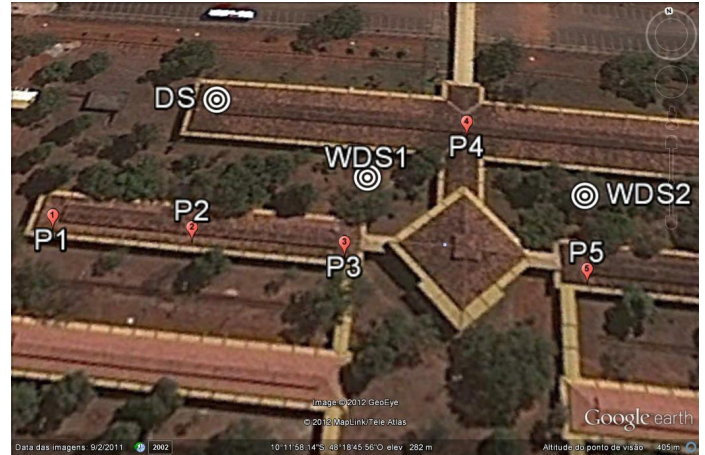


Fig. 4. Collection Points.

TABLE II
DISTANCE ACCESS POINTS

Checkpoint	AP	DISTANCE	HOPS
P1	DS	46,44	0
P2	WDS1	41,96	1
P3	WDS1	14,76	1
P4	WDS1	31,07	1
P5	WDS2	16,30	2

IV. METHODOLOGY

The study was realized in three steps: data collection, processing and analysis of the results.

A. Collection

The collection was realized in both environments through the accomplishment of the VoIP calls between two stations without mobility to fixed distances in pre-fixed points at IFTO. The points were locations where there is concentration of users from the network analysed, being these usually near to the classrooms or areas of free access. The collection began executing a pre-sample calls in the environment. It was adopted a fixed number of twenty calls, with the objective of indicating the number of necessary calls to be realized to a trustful degree of 95% (3). Each call made had the average duration of one minute between the stations. Below follows the formula for the sample calculation (2) used.

$$n = \left(\frac{Z \frac{\alpha}{2} \times \sigma}{E} \right)^2 \tag{2}$$

Where, n corresponds to the number of individuals on the sample, $Z_{\frac{\alpha}{2}}$ is the critical value that corresponds to the wished trust degree. σ is the swerve from the metric's population pattern studied and E corresponds to the maximum estimated error. The pre-sample realized of 20 calls was realized to define the size of initial sample to be realized in both environments in this study. With the pattern swerve of the calls and the maximum error admitted it was possible to find a sample size of 60 calls, according table II, for the second environment.

TABLE III
PRE-SAMPLE

	MEAN	STANDARD DEVIATION	ERROR	SAMPLE SIZE
<i>Delay</i>	36.53	9.04	2.3	60
<i>Jitter</i>	0.006	0.0008	0.06	42
<i>Throughput</i>	85.62	0.01	3	53

The metrics delay resulted in a sample size of 60 calls, being this the size adopted, inasmuch it comprehends the sample generated by the other metrics. The packet loss was not analysed inasmuch it generated a null loss, taking its invalid sample for the calculation of the sample size.

B. Analysis

The data analysis was realized with the use of the statistic software R and the shell script language. This processing had as an objective to provide the average central tendency and the pattern dispersion measurement of each service quality metric broached in this study. In the analysis was also realized the objective measuring of the call quality with the found results. With the first environment properly mounted the first collection of 60 calls can be realized. The calls were always made with station A as the origin. In each call, the wireshark software was executed with the purpose of capturing all the received and sent packets through the WLAN interface. In this environment, were generated 60 calls through one-day period in different time. All the capture files were saved in a directory for later analysis.

With the use of filters on wireshark, it was possible to realize the relevant data export used for the statistical calculations. They were: packet size, average time, protocol, ip origin address, ip destination address and RTP packet sequence. With the exported data of each call, it was realized the import of these files to the statistic software R. With the information of the imported calls we realized an exploratory analysis through descriptive average statistics, swerve-pattern in each one of the imported files, as in general we obtained the graphics of all made calls. With the calls from the first environment saved and converted to one of the formats accepted by the R software, we imported the 60 files realizing the calculations of the metrics

delay, jitter, packet loss and outflow. At the end of the analysis, we obtained 60 averages of each metric. The data obtained through the R tool will be illustrated in section 5. To estimate the population average of the metrics, it was used a break of 95% of trust (3).

$$\mu = \pm z \frac{\sigma}{\sqrt{n}} \tag{3}$$

Where, μ corresponds to the average of the population, z the number of pattern swerves in the table of normal distribution, σ corresponds to the pattern swerve of the population and n the number of elements in the sample.

V. RESULTS

The analysis of the calls presented in this study show the impact provoked use of VoIP in WLAN networks with the use of WDS. In the first environment the average values found are the values expressed in table IV.

A. Environment 1

TABLE IV
AMBIENT 1

	MIN	MEAN	MAX	STANDARD DEVIATION
<i>Delay</i>	19.98	19.99	20	0.002
<i>Jitter</i>	0.002	0.006	0.008	0.0008
<i>Throughput</i>	85.55	85.62	85.67	0.01
<i>Packet Loss</i>	0	0	0	0

In this environment we note the values of the metrics suitable to voice transmission, inasmuch the values attend the maximum requirements according to the recommendations of ITU-T. The delay average value found on the calls is within the maximum value accepted for the VoIP according to ITU-T – G.114's recommendation [12]. The variation of the delay is quite below of what is recommended, as well as the other metrics favoring this way the environment for the VoIP transmission. It is important to remember that this environment was analysed initially as a reference to be compared with the results of the second environment where the network's distribution is done using WDS. The variation of the delay in each call in this environment was relatively small, according to the illustration of picture 5. The small delay's variation can be justified by the circumstance of the environment being in use only by the two stations, that is, it did not occur any background traffic at the moment of the collection.

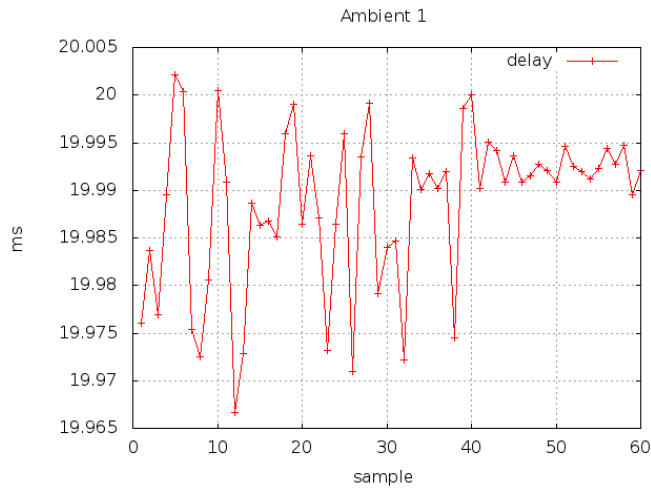


Fig. 5. Delay Mean

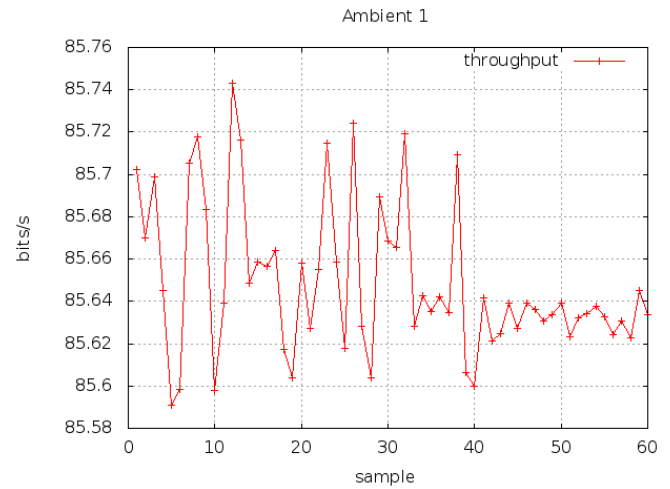


Fig. 7. Throughput Mean

The other metrics also had little variation on the realized calls sample. The jitter's average is expressed on picture 6.

To estimate the metric's average population collected in this study we used a gap of trust of 95%. Applying the formula (2) we achieved.

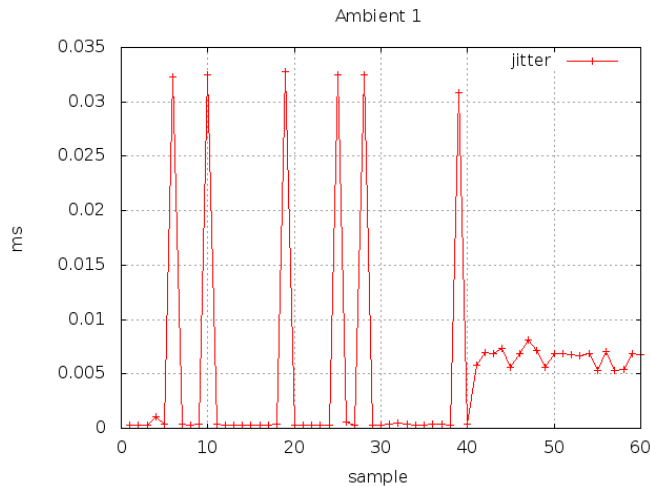


Fig. 6. Jitter Mean

TABLE V
CONFIDENCE INTERVAL

	LOWER ENDPOINT	MEAN	UPPER ENDPOINT	μ
Delay	19.9935	19.9942	19.9949	0.0007
Jitter	0.0063	0.0065	0.0067	0.0002
Throughput	85.6213	85.6246	85.6278	0.0032
Packet Loss	0	0	0	0

The average jitter on this environment was kept around 0.006 ms that is the time's variation in the packets delivery was very small. The loss found in this environment was null, as expected and confirmed. The average throughput was 85.62 bits/s was found in the sample and the same way of other metrics they remained constant and coherent to the environment without representing grand variations, according to picture 7.

The quality call measurement was realized in this study using the E-model. Initially it is necessary to know the scalar factor (R-factor) that varies from 0 to 100. The R factor is related with MOS as described on section 3 methodology. In this first environment we obtained the average factors.

TABLE VI
FACTOR R AND MOS

	FACTOR R MEAN	MOS
Ambient 1	70.36	3

All the calls made in the first environment had a quality average prediction on the scale MOS 3 that suggest the calls had a reasonable quality, where some users would be unsatisfied with that quality. This value was expected due to used codec in the G.722 study, being for this, expected a MOS on scale 3.

B. Environment 2

In the second environment collection the average values of the metrics are the values expressed by collection points. In the tables below are illustrated the resulting average values from five collection points.

TABLE VII
AMBIENT 2 - P1

	MIN	MEAN	MAX	STANDARD DEVIATION
Delay	19.98	20.51	20.96	0.31
Jitter	0.001	0.01	0.05	0.01
Throughput	81.66	83.46	85.66	1.27
Packet Loss	0	0.11	2.09	0.45

The point P1 was located roughly 46,44 meters of distance from the access point. A station was associated to WDS1 at the moment of the calls. The average delay in this environment was 20,51ms. Compared to the average delay in the first environment this corresponds to an increase of 2,60% on the average delay. The jitter metric had an increase of 172% in this collecting point compared to the environment without the WDS. The throughput had a loss of 2.52% when compared to the average throughput of the first environment. The metric packet loss had an average value of 0.1%. In the first environment we did not have packet loss.

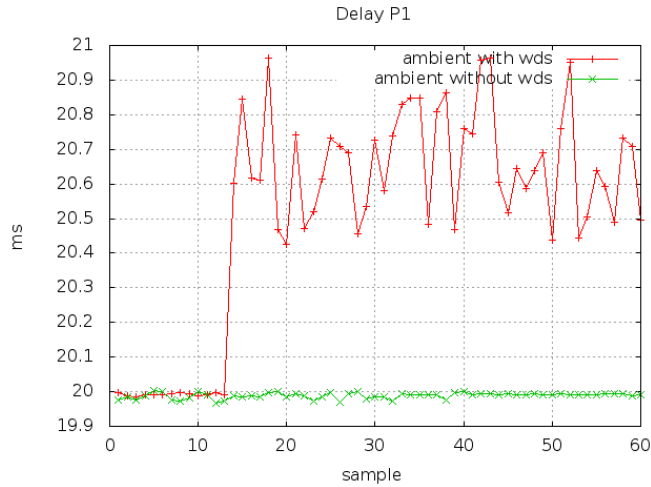


Fig. 8. Delay P1.



Fig. 9. Jitter P1.

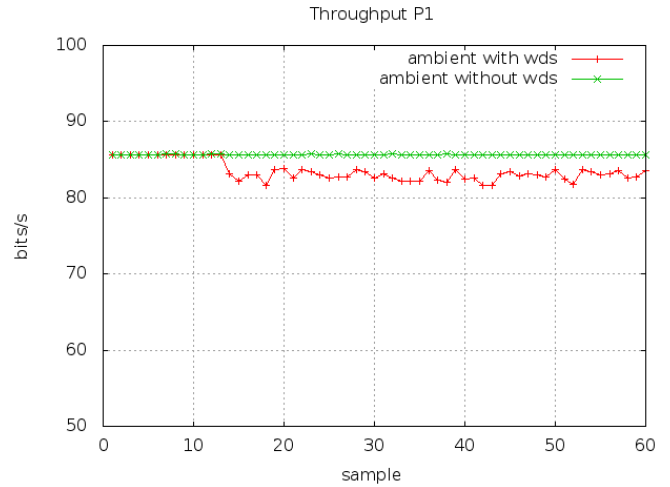


Fig. 10. Throughput P1.

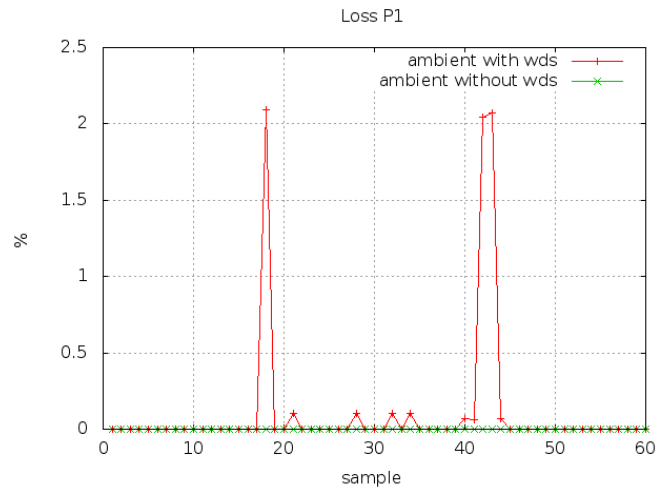


Fig. 11. Packet Loss P1.

Estimating the real average of the metrics population to a gap of 95% of trust in P1, we obtained:

TABLE IIX
CONFIDENCE INTERVAL

	LOWER ENDPOINT	MEAN	UPPER ENDPOINT	μ
Delay	20.4374	20.5159	20.5943	0.0784
Jitter	0.0149	0.0179	0.0209	0.0029
Throughput	83.1437	83.4662	83.7888	0.3225
Packet Loss	0.0010	0.1136	0.2284	0.1147

Measuring the quality of the realized calls in this point, we obtained:

TABLE IX
FACTOR R AND MOS

	FACTOR R MEAN	MOS
Ambient 2 - P1	69.84	2

Comparing the MOS obtained in the first environment with MOS of the P1 point was found the R factor equal to 69.84,

resulting in a inferior scale of the realized calls in the environment without WDS. Such fact can be justified due to the station being associated to the WDS1, where there is a jump between the access points to reach the PBX.

The second collection point, P2 was at a rough distance of 41.96 meters from the access point WDS1. The metric's average is illustrated on table X.

TABLE X
AMBIENT 2 – P2

	MIN	MEAN	MAX	STANDARD DEVIATION
Delay	19.98	20.29	21.48	0.39
Jitter	0.0006	0.009	0.038	0.007
Throughput	79.68	84.38	85.66	1.61
Packet Loss	0	0.0051	0.17	0.02

The metric's delay had an increase of 1.51% in the average when compared to the environment 1. Jitter had an increase of 44.27%. Throughput had an average of 1.45% inferior to the obtained in environment 1. Packet loss had an increase of 0.005% in this point.

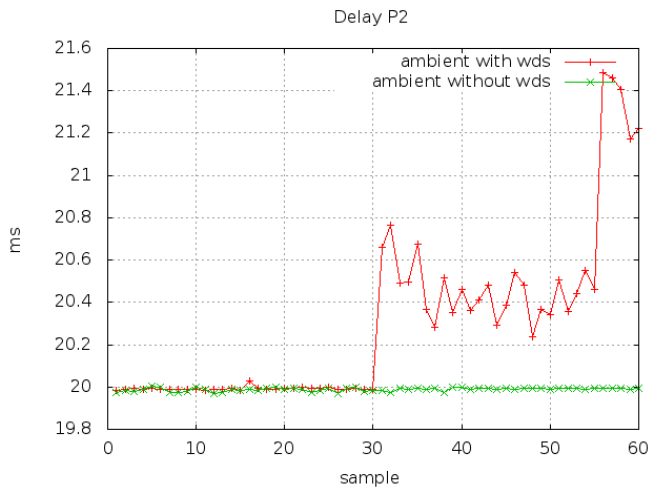


Fig. 12. Delay P2.

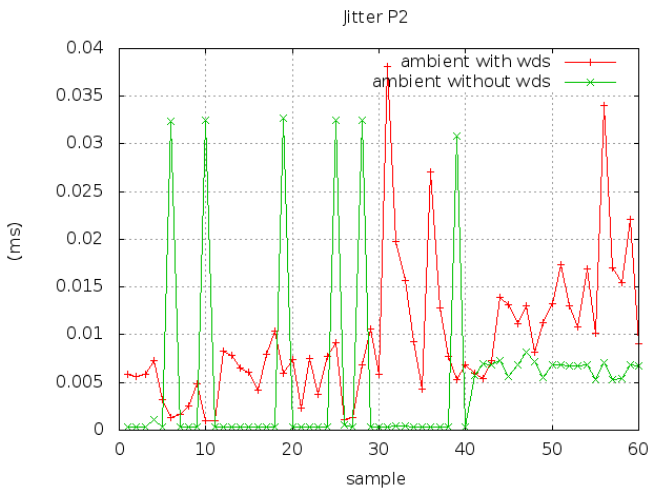


Fig. 13. Jitter P2.

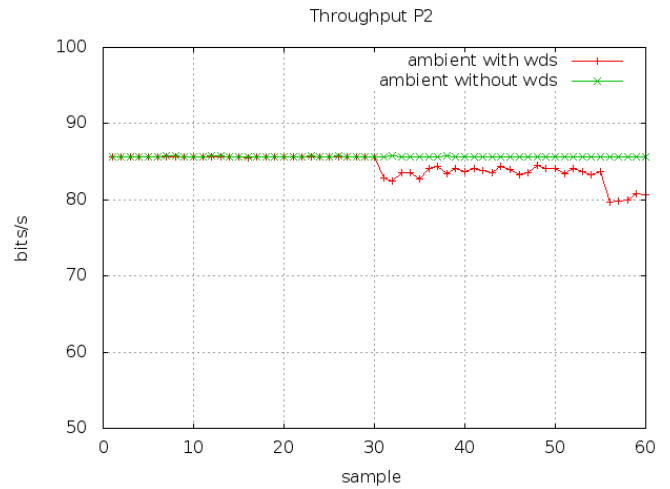


Fig. 14. Throughput P2.

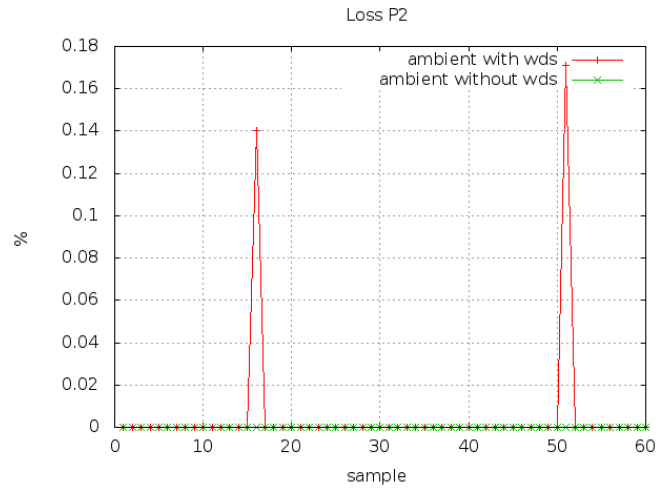


Fig. 15. Packet Loss P2.

Estimating the population average of the metrics in P2, we obtained:

TABLE XI
CONFIDENCE INTERVAL

	LOWER ENDPOINT	MEAN	UPPER ENDPOINT	μ
Delay	20.1957	20.2966	20.3974	0.1008
Jitter	0.0076	0.0094	0.0113	0.0018
Throughput	83.9722	84.3800	84.7877	0.4077
Packet Loss	0.0019	0.0051	0.0123	0.0071

Measuring the quality of the calls realized in this point, we obtained:

TABLE XII
FACTOR R AND MOS

	FACTOR R MEAN	MOS
Ambient 2 – P2	70.06	3

The MOS obtained in P2 was the same obtained in P1. The rising of the average of delays and jitter can be justified too by the additional jump now realized in this collection point to reach the PBX. This jump inserted a significant delay and jitter in the

calls, this way the MOS was obtained due to the scale for the obtained value 3 comprehend values between 70 and 80 for the R factor.

The collection point P3 was at a distance of 14.73 meters from the WDS1. The average of the metrics is expressed on table XIII.

TABLE XIII
AMBIENT 2 – P3

	MIN	MEAN	MAX	STANDARD DEVIATION
Delay	20.32	20.64	21.31	0.18
Jitter	0.000004	0.014	0.034	0.007
Throughput	80.33	82.94	84.21	0.75
Packet Loss	0	0.16	4.78	0.76

In this point the average delay had an increase of 3.24% compared to the first environment. Jitter had an increase of 125.05%. Throughput had an average of 3.13% less when compared to environment 1. Packet loss had an increase of 0.16%.



Fig. 16. Delay mean in P3.

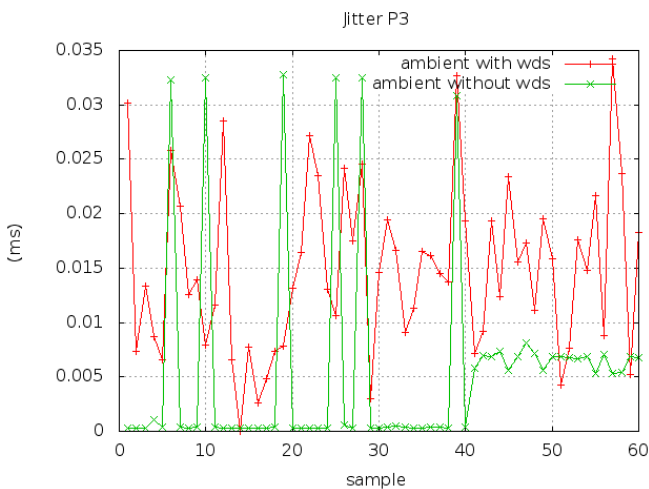


Fig. 17. Jitter mean in P3

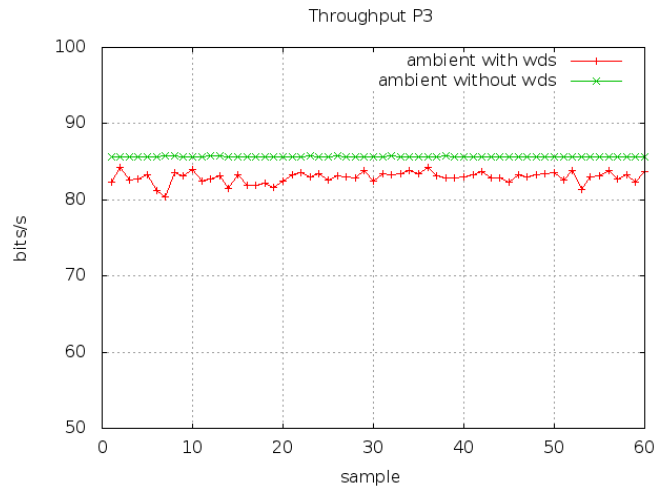


Fig. 18. Throughput mean in P3.

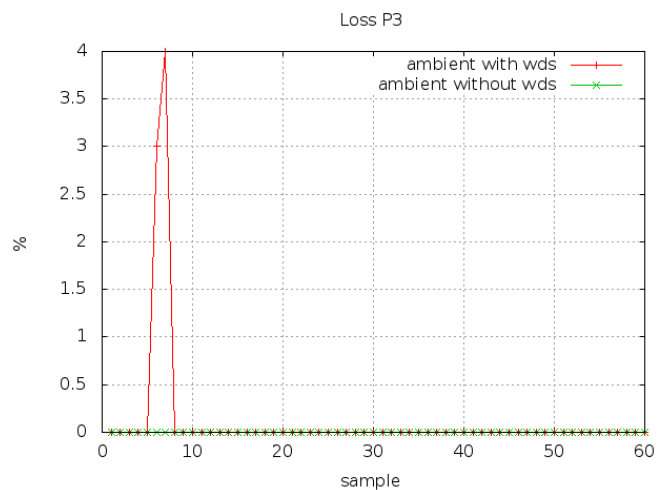


Fig. 19. Packet loss mean in P3.

Estimating the average population of the metrics in P3, according to table XIV, and calculating the MOS we obtained:

TABLE XIV
CONFIDENCE INTERVAL

	LOWER ENDPOINT	MEAN	UPPER ENDPOINT	μ
Delay	20.5945	20.6424	20.6904	0.0479
Jitter	0.0128	0.0148	0.0167	0.0019
Throughput	82.7518	82.9425	83.1332	0.1907
Packet Loss	0.0262	0.1683	0.3629	0.1946

TABLE XV
FACTOR R AND MOS

	FACTOR MEAN	MOS
Ambient 2 – P3	69.71	2

In P3 the collection was realized near to the access point. In this point we obtained a MOS equal 2. This loss in performance can be justified by the raise of the average delay and jitter, what degraded the quality of the call. The fourth collecting point P4 is located at 31.07 meters from the access point WDS1. In this

point we obtained the following averages:

TABLE XVI
AMBIENT 2 – P4

	MIN	MEAN	MAX	STANDARD DEVIATION
Delay	19.99	20.60	22.10	0.42
Jitter	0.003	0.016	0.041	0.009
Throughput	77.44	83.10	85.64	1.66
Packet Loss	0	0.03	2.05	0.26

In P4 the average delay had an increase of 3.07% in relation to the first environment. Jitter had an increase of 153.21%. Throughput an average of 2.94% less when compared to environment 1. The packets loss in this collection point was 0.034%.

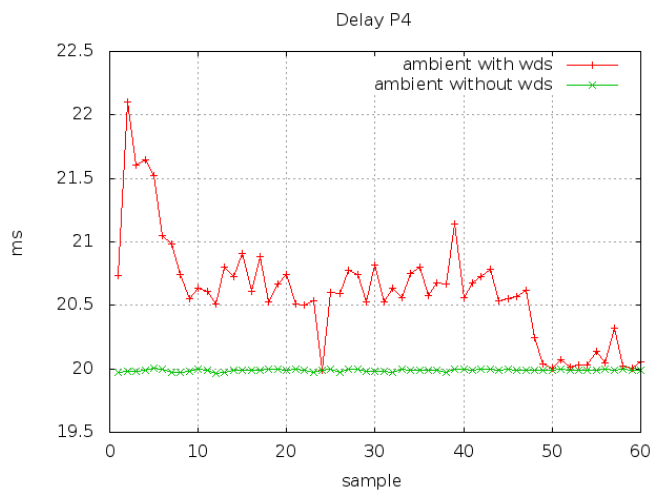


Fig. 20. Delay mean in P4.

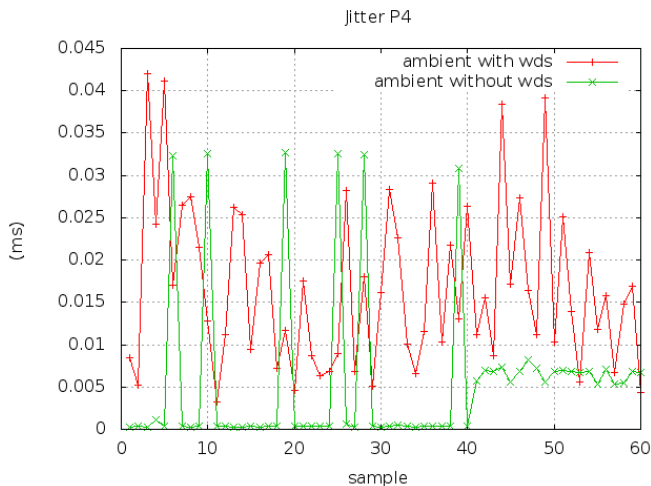


Fig. 21. Jitter mean in P4.

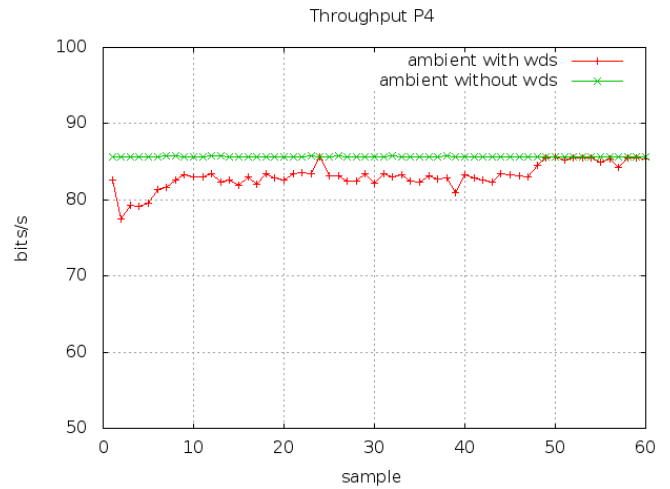


Fig. 22. Throughput mean in P4.

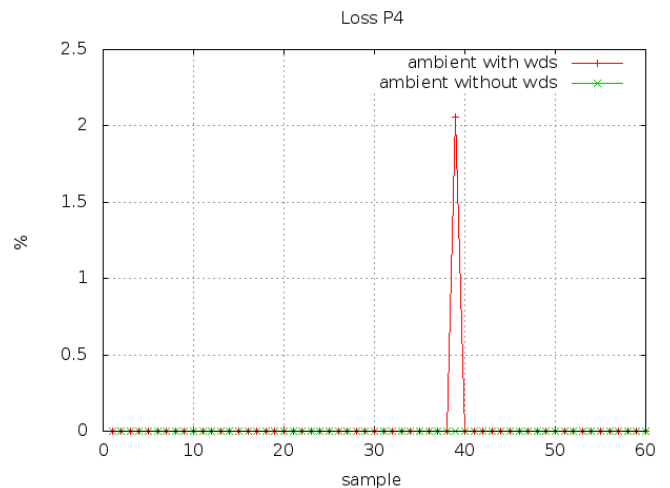


Fig. 23. Packet loss mean in P4.

Estimating the population average of the metrics in P4 (see table XVII), and calculating MOS (see table XVIII) we obtained:

TABLE XIV
CONFIDENCE INTERVAL

	LOWER ENDPOINT	MEAN	UPPER ENDPOINT	μ
Delay	20.5025	20.6091	20.7156	0.1065
Jitter	0.0142	0.0166	0.0191	0.0024
Throughput	82.6813	83.1035	83.5256	0.4221
Packet Loss	0.0328	0.0342	0.1013	0.0671

Measuring the quality of the calls made in this point, we obtained:

TABLE XVIII
FACTOR R AND MOS

	FACTOR R MEAN	MOS
Ambient 2 – P4	69,75	2

In the collection point P4 we obtained a R factor equal to 69.75. This value led the MOS to be measured on a scale like 2,

what turns the quality call bad for many users. The collection point P5 was at a distance of 16.30 meters from WDS2. In this collection the packets transmitted through the station makes use of two jumps to reach DS.

TABLE XIX
AMBIENT 2 – P5

	MIN	MEAN	MAX	STANDARD DEVIATION
Delay	20,54	22,78	28,65	1,84
Jitter	0,00001	0,028	0,063	0,012
Throughput	59,74	75,57	83,32	5,62
Packet Loss	0	0,98	24,97	3,42

In P5 the average delay had an increase of 13.97% in relation to the first environment. In this collection we computed the worst performance for the metric's delay. Jitter had an increase of 326% compared to the first environment. Throughput had an average of 11.78% less than when compared to the first environment. Packet loss was computed in 0.98%.

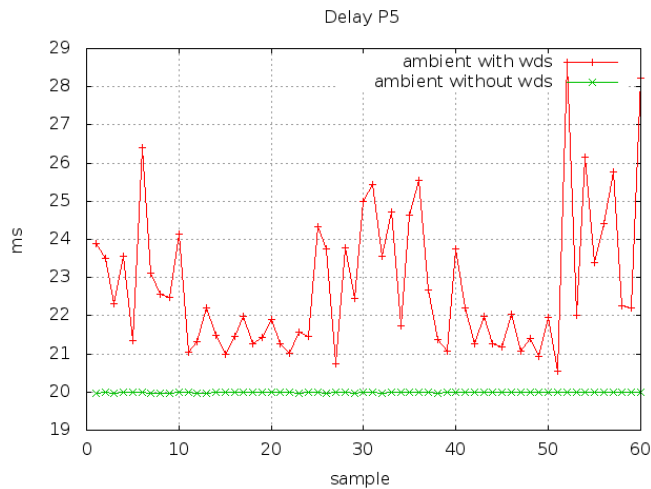


Fig. 24. Delay mean in P5.



Fig. 25. Jitter mean in P5.

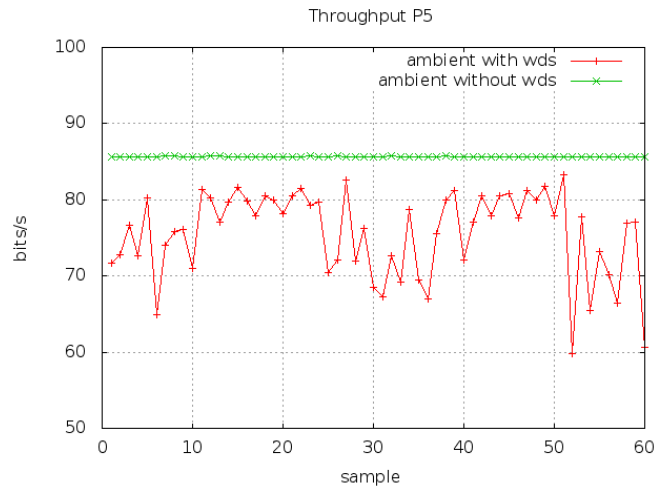


Fig. 26. Throughput mean in P5.

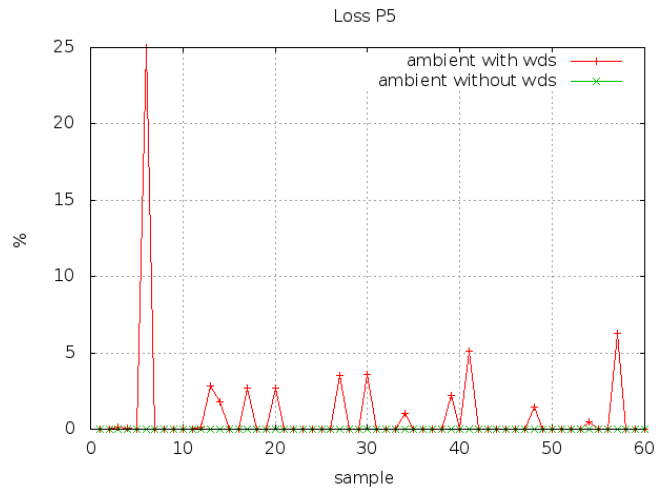


Fig. 27. Packet loss mean in P5.

TABLE XIV
CONFIDENCE INTERVAL

	LOWER ENDPOINT	MEAN	UPPER ENDPOINT	μ
Delay	22.3216	22.7876	23.2537	0.4660
Jitter	0.0248	0.0280	0.0313	0.0032
Throughput	74.1502	75.5734	76.9966	1.4232
Packet Loss	0.1170	0.9831	1.8492	0.8661

TABLE XXI
FACTOR R AND MOS

	FACTOR MEAN	MOS
Ambient 2 – P5	67,57	2

In P5 was observed the worst performance among the five collection points. This fact can be justified due to the transited packets among the stations make use of the 2 jumps using the access points WDS2 and WDS1 to reach the PBX. This additional jump influenced directly in the outflow's performance, increase of the delay and jitter, as well as the loss began to have a considerable value at this point.

VI. FINAL CONSIDERATIONS

In this study we analysed the use of VoIP applications in WLAN environments with and without using WDS. Through the execution of calls in two environments we observed and computed significant differences on the analysed metrics (see table XXII). In both environments analysed we found the metrics favorable for voice transmissions on IP networks.

TABLE XXII
ALL AMBIENTS

	DELAY	JITTER	THROUGHPUT	PACKET LOSS
<i>Ambient 1</i>	19,9942	0,0065	85,62	0
<i>Ambient 2 P1</i>	20,5159	0,0179	83,46	0,113
<i>Ambient 2 P2</i>	20,2966	0,0094	84,38	0,005
<i>Ambient 2 P3</i>	20,6424	0,0148	82,94	0,168
<i>Ambient 2 P4</i>	20,6091	0,0166	83,10	0,034
<i>Ambient 2 P5</i>	22,7876	0,0280	75,57	0,983

We observed in the environment where WDS is practiced the difference in the computed metrics. These metrics have different values when the collection point is using other points to take the packets to the DS. In our study the collection point P5 was the only one analysed in what the packets transmitted need to pass through two access points to reach the DS. It is possible that exists a relation between the number of jumps and the use of WDS. We observed the different metrics in environments with a number of jumps superior to 1. These metrics were observed on point P5 where the delay's average suffered a considerable growth. The other metrics also had its average values altered. Jitter had an increase and throughput suffered a loss. Packet loss came close to 1%.

VII. FUTURE ASSIGNMENTS

As future assignments we aim yet to realize the measurement in other 5 points scattered through IFTO. In these additional points we expect to find metrics that degrade even more the VoIP applications. These 5 points use a higher quantity of jumps between the access points to reach the DS. As a future assignment it remains to use a multiple regression model to estimate the MOS using the variables of QOS looking for a relation between the analysed variables.

Other assignment to be realized in this same environment is to make calls with the stations in movement. We tried to observe the variations of the metrics at the moment of the change of BSS, looking to compute the delay and the influence of it in the VoIP applications.

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A Hybrid Chaos- Fuzzy -Threshold Steganography Algorithm for Hiding Secure Data

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Abstract— Security problem is an essential requirement for data transmission. Although the will known methods of data encryption attain certain security levels, they make the encrypted data unreadable, and unnatural, this attracts some unintended observer attention. So it is required to search for a higher security approach. The present paper introduces a new hybrid steganography algorithm to achieve a higher level of security. The proposed algorithm consists of a compound processing using Chaos – Fuzzy- Thresholding steganography method (CFT). Implementation of the proposed CFT hybrid algorithm shows a higher degree of security level. The hidden data reconstruction is based on an inverse CFT steganography algorithm processing.

Index Terms— Chaos, Steganography, Fuzzy, thresholding

I. INTRODUCTION

Some confidential data might be stolen, copied, modified or destroyed by an unintended observer. Therefore, security problems become an essential issue. Encryption is a well-known procedure for secure data transmission. The frequently used encryption methods include RSA and DES algorithms. Although these two methods achieve certain security effects, they make the secret messages unreadable and unnatural. These unnatural messages usually attract some unintended observer's attention. This is the reason a new security approach called "Steganography" arises [1,2]. Steganography literally means covered writing and is the art of hiding secret messages within another seemingly innocuous message, or carrier [3]. With the advent of digital technology, the list of carriers has been made to include, images, text, e-mails, audio and video messages. Some Steganography utilities use secret keys. It can distinguish two kinds of keys: steganographic keys and cryptographic keys [4]. A steganographic key controls the embedding and extracting process. For example, it can scatter the message to be embedded over a subset of all suitable places in the carrier

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medium. Without the key, this subset is unknown, and each sample used to detect embedding by a statistical attack is a mixture of used and unused places which spoils the result. A cryptographic key is used to encrypt/decrypt the message [5,6]. This paper describes a new method of steganography technique for hiding large volumes of data using digital images, text, and audio as a cover medium. Before embedding the message in the cover medium, a logistic map chaotic encryption technique are used to obtain an undefined (encrypted) message then compress the image color (or data) range using Fuzzy logic compressor and embed the message in the cover media by using the proposed steganography method. This will be discussing in the next section in this work.

II. THEORITICAL DESCRIPTION

To provide a Theoretical description of steganography, terms and concepts should first be explained an overview of the different kinds of steganography is given at a later stage. Some definitions common to the steganography field: cover medium, this is the medium in which the data hide for it. Embedded message, this is the hidden message that want to put it in the cover medium. Stego-key, this is represented by some secret information, which is needed in order to extract the embedded message from the stego-medium. Stego-medium, this is the final piece of information that the casual observer can see. We can define this simple formula,

$$\text{cover medium} + \text{embedded message} = \text{stego_message.}$$

There are two general approaches to classify steganographic systems. The first approach is based on the type of cover file while the second approach is based on the hiding method or the layout of modification used in the embedding process [7]. These two general classification approaches of steganography are explained as follows, Cover-Type Based Classification, Since many kinds of digital media can be used as cover files of steganography, the first approach of classification breaks down steganography according to the type of the cover file used. However, the properties of these cover files vary from one type to another and these properties control how the secret data can be hidden in these cover files. To this end, knowing the type of cover file can give us an indication or idea where the secret data might be hidden. Mostly, steganographic systems are classified according to the cover file used. Accordingly, different steganography types can be distinguished such as: image, audio, video, text, and

HTML steganography [7]. Hiding Method-Based Classification, Regardless of the cover type used for data hiding, steganography can be classified according to the method used to hide secret data. Furthermore, this approach of steganography classification is the most preferred approach in the steganography research community. Accordingly, there are three ways to hide secret data in cover files: insertion based, substitution-based, and generation-based method [8].

Many steganography techniques have been proposed during the last few years. These techniques differ in the mechanism or principle being used to hide a secret message. Therefore, there are six categories of steganography techniques: spread spectrum techniques, statistical methods, distortion techniques, cover generation techniques, substitution systems, and transform domain techniques [9]. Spread spectrum communications define as "the process of spreading the bandwidth of a narrowband signal across a wide band of frequencies". In spread spectrum steganography, the frequency domain of the cover file is considered to be a communication channel and the secret message as a signal that is transmitted through it. Since the secret message is spread through a wide frequency band, this technique is relatively robust against stego file modification or message removal [9]. Statistical Techniques embed only one bit of secret data in a cover file. Therefore, it is known as "1-bit" steganography scheme. If "1" is hidden in a cover file, some statistical characteristics (e.g. entropy and probability distribution) of this cover file must be changed significantly to clearly indicate the existence of a message. However, if the hidden bit is "0", the cover file is left unmodified. Therefore, this technique entirely depends on the ability of the receiver to differentiate between changed and intact cover files [7, 9]. Distortion Techniques, which means that a receiver does not need the original cover file to extract the hidden message from the corresponding stego file. However, if a distortion technique is used, the receiver requires the original cover file in order to recover the secret message. For a receiver, the embedded message is the difference between the modified cover file received (the stego file) and the original cover file [6]. Cover Generation Techniques is preventing such kind of detection since only stego files are available and there is no cover files used. The major limitation of this method is the limited stego files which can be generated. Moreover, the generated stego files might be unrealistic files for end users (e.g. an image contains different shapes and colors without any sense or a text without any meaning). Therefore, the main media for such techniques are random-looking images and English text files [6]. Substitution Systems, it is important to find out some areas or data that can be modified without having any significant effects on this cover file. Therefore, a secret message can be embedded by replacing the redundant or insignificant parts of a cover file with secret message bits, without adding any significant noise to this cover file. Generally, digital covers have a large number of redundant bits (e.g. least significant bits (LSB)) [9]. In the substitution technique of steganography, the bits of the secret message substitute the LSB of the bytes of the cover file without causing a drastic change to this cover file. Moreover, the LSB technique is a spatial domain technique since it embeds the secret bits directly in the cover file. Since LSB substitution

technique is relatively quick and easy to use, it is the most common technique used for digital steganography and especially with digital images. However, the embedded information using the LSB technique is highly vulnerable for images as a covering media, the LSB of a pixel is replaced with an M's bit. If we choose a 24-bit image as cover, we can store 3 bits in each pixel by modifying the LSBs of R, G and B array. To the human eye, the resulting stego image will look identical to the cover image [11, 12, 13]. Transform Domain Techniques unlike spatial domain techniques (e.g. LSB technique), transform (frequency) domain techniques hide secret data in significant parts of the cover file. Therefore, frequency domain techniques are considered more robust to attacks than spatial domain techniques. Hence, most of robust steganographic systems known today rely on frequency domain techniques. There are many transforms used to map a signal into the frequency domain. Discrete cosine transforms (DCT), discrete wavelet transforms (DWT), and discrete Fourier transform (DFT) are methods used as mediums to embed secret data in digital images. However, when we add a slight noise or secret data to some frequency domain components, it changes the whole image rather than changing only this part of the image. Thus, secret and embedded data will be spread across the entire image and will not be concentrated on one certain area or region [13, 14, 15].

A. Chaotic Mapping

Chaos is a dynamical system that is extremely sensitive to its initial conditions. It is a deterministic nonlinear system that has random-like behaviours. Chaos theory has become a new branch of scientific studies today. Discrete chaotic dynamic systems are used in this system. The implemented map is logistic map, which is one of the simplest form of one dimensional chaotic maps and mathematically its equation can be written as [13]:

$$w_{i+1} = \mu w_i (1 - w_i) \tag{1}$$

where w_i is a real value in (0,1), and μ is bifurcation parameter satisfying $0 \leq \mu \leq 4$. The logistic map is chaotic on the condition $0.35699 \leq \mu \leq 4$.

B. Fuzzy Logic Compressor

Fig. 1. shows the basic structure of a Fuzzy logic system. The main building units are a fuzzification unit, a Fuzzy logic reasoning unit, a knowledge base, and a defuzzification unit. Defuzzification is the process of converting inferred Fuzzy control actions into a crisp control action. The fuzzy knowledge-base has a rule-base that maps a Fuzzy inputs variable, E , into a Fuzzy output, U [16].

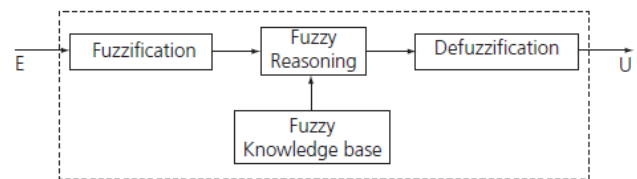


Fig. 1. Basic Structure of a Fuzzy Logic Controller (FLC)
 This can be expressed by a linguistic statement such as:
 $E \rightarrow U$ (conditions E implies condition U)
 which may be written as:

$$\text{IF } E \text{ THEN } U.$$

The Fuzzy knowledge-base also has a database defining the variables. A Fuzzy variable is defined by a Fuzzy set, which in turn is defined by a membership function. Fuzzy reasoning is used to infer the output contributed from each rule. The Fuzzy outputs reached from each rule are aggregated and defuzzified to generate a crisp output. In the design of an FL system it is assumed that, a solution exists, the input and output variables can be observed and measured, an adequate solution is acceptable, and a linguistic model can be created based on the knowledge of a human expert. In order to model a system linguistically, one needs to identify the input and output variables of the process to be controlled and define subsets that cover the universe of discourse of each variable and assign a linguistic label to each one. For example, the linguistic variable *speed* may be defined as three Fuzzy subsets: *slow*, *medium*, and *fast* as shown in Fig. 2. Form a rule-base by assigning relationships between inputs and outputs. Determine a defuzzification method to be used to generate a crisp output from the Fuzzy outputs generated from the rule-base.

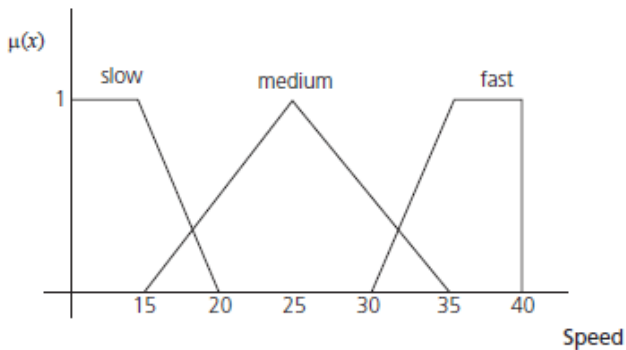


Fig. 2. Possible graphical representation of Fuzzy sets [18]

C. Membership Functions

Discrete and continuous membership functions of a Fuzzy set are intended to capture a person’s thinking. Fuzzy membership functions can still be determined subjectively in practical problems based on an expert’s opinion. In such a situation one can think of membership functions as a technique to formalize empirical problem solving that is based on experience rather than the knowledge of theory. The expert’s way of thinking can be captured either directly or through a special algorithm. Such determination could become more focused by physical measurements if the need arises. Available frequency histograms and other probability data can also help in constructing the membership function. It is important, however, to note that membership function values, or grades of membership, are not probabilities and they do not have to add to 1. Membership construction can be further simplified by selecting their form from the smaller family of the commonly used ones.

D. Fuzzification

Fuzzification is the process of making a crisp quantity Fuzzy. We do this by simply recognizing that many of the quantities that we consider to be crisp and deterministic are actually not deterministic at all; they carry considerable uncertainty. If the

form of uncertainty happens to arise because of imprecision, ambiguity, or vagueness, then the variable is probably Fuzzy and can be represented by a membership function [16].

E. Defuzzification

For a given input, several IF/THEN rules could be launched at the same time. Each rule would have a different strength, because a given input may belong to more than one Fuzzy set, but with different membership values. In general, the output of the Fuzzy reasoning would involve more than two Fuzzy sets; therefore, one can write:

$$F = \bigcup_{i=1}^k F_i \tag{2}$$

Assuming the support of F is $X = \{x_1, x_2, x_3, \dots\}$ then for $x_i \in X$, $F(x_i) = w_i$ indicates the degree to which each is suggested by the rule-base as a good output for the given input. The defuzzification operation is applied on F to determine the best crisp output. Numerous defuzzification methods have been suggested in the literature; however, sometimes different authors name the same method differently. No method has proved to be always more advantageous than the others. The selection of which method to use depends primarily on the experience of the designer [17].

F. Centroid method

This method is also known as the *centre of mass*, or *centre of gravity* method. It is probably the most commonly used defuzzification method. The defuzzified output, x^* is defined by,

$$x^* = \frac{\int \mu_F(x) x dx}{\int \mu_F(x) dx} \tag{3}$$

where the symbol \int denotes algebraic integration. Fig. 3. Represent this method graphically [18].

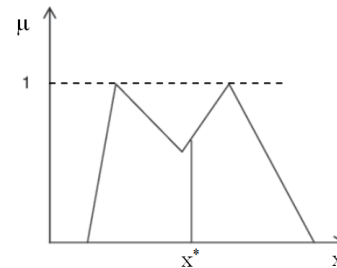


Fig. 3. Centroid Method

G. Centre of largest area method

This method is applicable when the output consists of at least two convex Fuzzy subsets which do not overlap. The result is biased towards a side of one membership function.

III. THE PROPOSED METHOD

The proposed steganography algorithm started with increasing the original image pixels from byte to word color capacity, and then distributes the hidden-image pixel randomly within the lower byte of the cover image pixels using chaos

distribution. Then this stego image processed using Fuzzy logic compressor to invert and compress its color range over a specific threshold color decided by the value of the upper significant bits of the image i.e. 192 to 255. The stego-image then is ready for transmission. The original image is separated from the received stego-image at the first stage of the receiver and invert and expand the color range using Fuzzy logic decompressor. The initial condition of the chaotic random sequence is used to collect the stego-image from the lower byte of the pixels. Then the hidden-image is reconstructed. Fig. 4. demonstrates the proposed method graphically. The same idea is performed with any kind of data such as text or sound signals.

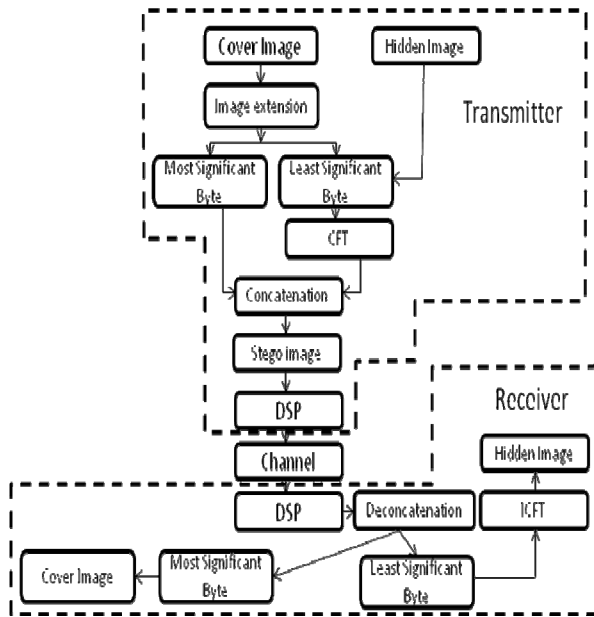


Fig. 4. The proposed Steganography algorithm

IV. RESULTS

The input and output membership functions of the proposed Fuzzy logic compressor (FLC) and Fuzzy logic Decompressor (FLD) is shown in Fig. 5. Fig. 6 demonstrate the transfer characteristics of the compressor and decompressor. To verify the effectiveness of the proposed method, it has been implemented on two different test images with two hidden-images. Fig. (7,8), (a) shows the original cover image before processing, (b) illustrate the hidden image before processing, (c) the chaos based distributed hidden image, (d) the compressed image (e) demonstrate the stego-image after embed the hidden image chaotically and compressed within its pixels, and (f) shows the reconstructed image after reconstruction from the stego-image. The mean square error (MSE) for the first image is 5.9143e+004 which achieve 48.16 dB peak signal to noise ratio (PSNR), MSE for the second image is 5.2445e+004 which achieve 49.13 dB peak signal to noise ratio (PSNR). These values of PSNR are acceptable for hiding the image data and can't notice by inspection.

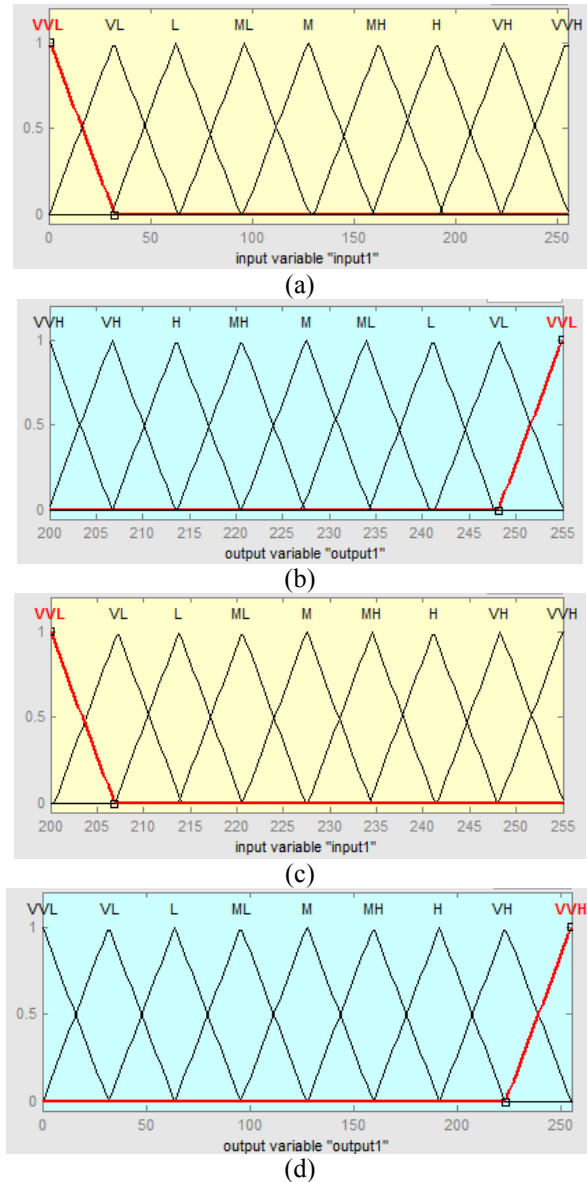


Fig. 5. Membership functions (a) input of the FLC, (b) output of the FLC, (c) input of the FLD, and (d) output of the FLD

V. CONCLUSION

The paper introduced a new hybrid chaos-Fuzzy-thresholding (CFT) steganography algorithm for hiding the multimedia data, image, text, or sound. The algorithm coordinates the data in the image dimensions using chaos distribution arrangement and performs a negative color compression using Fuzzy logic Scheme. The data is embedded with the original image in the pixels least significant bits, so can't appears within the image. The received image is separated and color expanded then rearranged using the initial condition of the chaos coordination. The algorithm is implemented using Matlab program for two test images. The results show a good hiding for the tested data in the original images with high degree of security if steganalysis is performed on the composed original image.

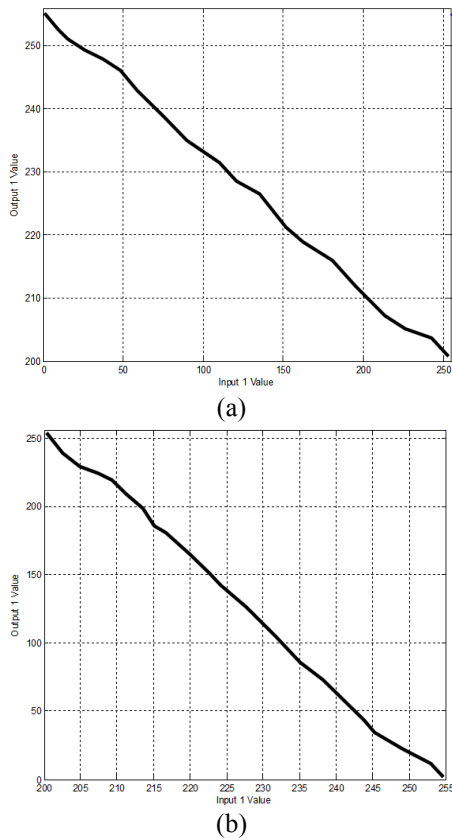


Fig. 6. Fuzzy logic transfer characteristics (a) T.C. of the FLC, and (b) T.C. of the FLD

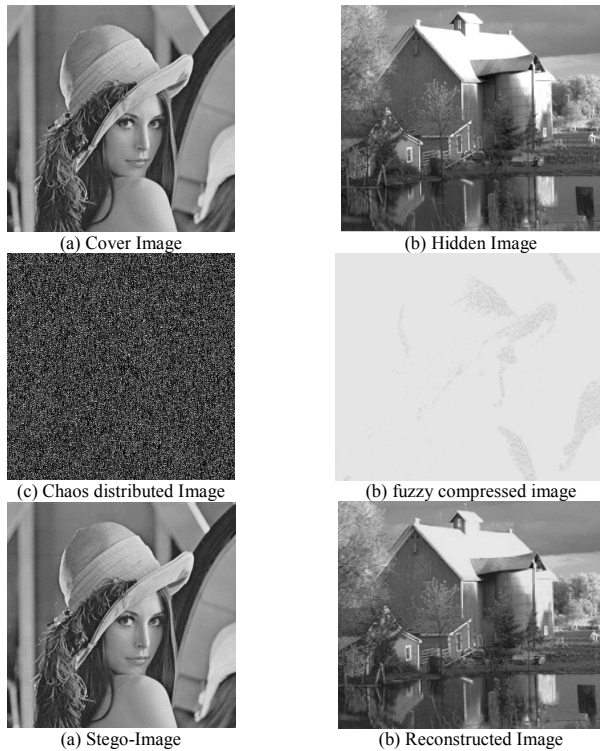


Fig. 7. stages of test image (1)

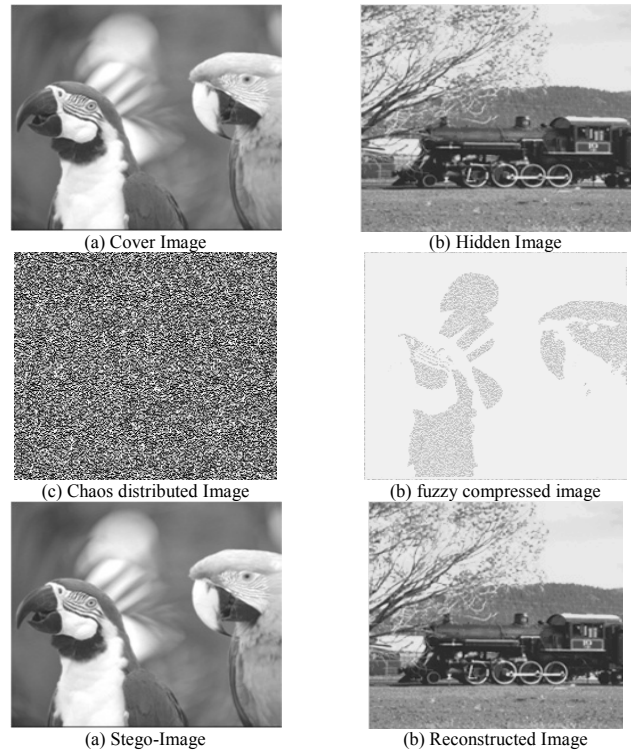


Fig. 8. Stages of test image (2)

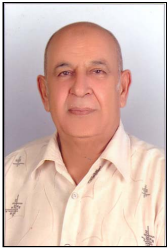
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