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Global IT Research Institute

Journal Editorial Board

Editor Guide

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All the editor group members are to be assigned as a evaluator(editor or reviewer) to submitted journal papers at the discretion of the Editor-in-Chief. It will be informed by eMail with a Member Login ID and Password.

Once logined the Website via the Member Login menu in left as a evaluator, you can find out the paper assigned to you. You can evaluate it there. All the results of the evaluation are supposed to be shown in the Author Homepage in the real time manner. You can also enter the Author Homepage assigned to you by the Paper ID and the author's eMail address shown in your Evaluation Webpage. In the Author Homepage, you can communicate each other efficiently under the peer review policy. Please don't miss it!

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For each paper that the editor-in-chief gets assigned, the Secretariat of ICACT Journal will send the editor an eMail requesting the review process of the paper.

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Editor-in-Chief will assign a evalaution group(a Editor and 2 reviewers) in a week upon receiving a completed Journal paper submission. Evaluators are given 2 weeks to review the paper. Editors are given a week to submit a recommendation to the Editor-in-Chief via the evaluation Webpage, once all or enough of the reviews have come in. In revision case, authors have a maximum of a month to submit their revised manuscripts. The deadlines for the regular review process are as follows:

Evalution Procedure	Deadline
Selection of Evaluation Group	1 week
Review processing	2 weeks
Editor's recommendation	1 week
Final Decision Noticing	1 week

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Editor will make a decision on the disposition of the manuscript, based on remarks of the reviewers. The editor's recommendation must be well justified and explained in detail. In cases where the revision is requested, these should be clearly indicated and explained. The editor must then promptly convey this decision to the author. The author may contact the editor if instructions regarding amendments to the manuscript are unclear. All these actions could be done via the evaluation system in this Website. The guidelines of decisions for publication are as follows:

Decision	Description
Accept	An accept decision means that an editor is accepting the paper with no further modifications. The paper will not be seen again by the editor or by the reviewers.
Reject	The manuscript is not suitable for the ICACT TACT publication.
Revision	The paper is conditionally accepted with some requirements. A revision means that the paper should go back to the original reviewers for a second round of reviews. We strongly discourage editors from making a decision based on their own review of the manuscript if a revision had been previously required.

■ Role of the Reviewer

Reviewer Webpage:

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You are given 2 weeks for the first round of review and 1 week for the second round of review. You must agree that time is so important for the rapidly changing IT technologies and applications trend. Please respect the deadline. Authors undoubtedly appreciate your quick review.

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Do not identify yourself or your organization within the review text.

Review:

Reviewer will perform the paper review based on the main criteria provided below. Please provide detailed public comments for each criterion, also available to the author.

- How this manuscript advances this field of research and/or contributes something new to the literature?
- Relevance of this manuscript to the readers of TACT?
- Is the manuscript technically sound?
- Is the paper clearly written and well organized?
- Are all figures and tables appropriately provided and are their resolution good quality?
- Does the introduction state the objectives of the manuscript encouraging the reader to read on?
- Are the references relevant and complete?

Supply missing references:

Please supply any information that you think will be useful to the author in revision for enhancing quality of the paperor for convincing him/her of the mistakes.

Review Comments:

If you find any already known results related to the manuscript, please give references to earlier papers which contain these or similar results. If the reasoning is incorrect or ambiguous, please indicate specifically where and why. If you would like to suggest that the paper be rewritten, give specific suggestions regarding which parts of the paper should be deleted, added or modified, and please indicate how.

Journal Procedure

Dear Author,

- **You can see all your paper information & progress.**

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Using the Submit button, submit your journal paper through ICACT Website, then you will get new paper ID of your journal, and send your journal Paper ID to the Secretariat@icact.org for the review and editorial processing. Once you got your Journal paper ID, never submit again! Journal Paper/CRF Template

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Using the evaluation system in the ICACT Website, the editor, reviewer and author can communicate each other for the good quality publication. It may take about 1 month.

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Status	Action
Acceptance	Go to next Step.
Revision	Re-submit Full Paper within 1 month after Revision Notification.
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So far it's free of charge in case of the journal promotion paper from the registered ICACT conference paper! But you have to regist it, because you need your Journal Paper Registration ID for submission of the final CRF manuscripts in the next step's process. Once you get your Registration ID, send it to Secretariat@icact.org for further process.

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Journal Submission Guide

All the Out-Standing ICACT conference papers have been invited to this "ICACT Transactions on the Advanced Communications Technology" Journal, and also welcome all the authors whose conference paper has been accepted by the ICACT Technical Program Committee, if you could extend new contents at least 30% more than pure content of your conference paper. Journal paper must be followed to ensure full compliance with the IEEE Journal Template Form attached on this page.

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Step 3. Review	Upon completing the confirmation, it gets started the review process thru the Editor & Reviewer Guideline. Whenever you visit the Author Homepage, you can check the progress status of your paper there from start to end like this, " Confirm OK! -> Gets started the review process -> ...", in the Review Status column. Please don't miss it!

Volume. 4 Issue. 3

Open IPTV Convergence Service Creation and Management using Service Delivery Platform

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***Abstract*—IPTV brought a new digital era in the broadcasting domain. The main change of digital broadcasting is an advent of a bi-directional interactive service feature. Using that bi-directionality, IPTV provides various kinds of convergence service such as information providing, advertisement, and e-commerce. But the number of services required to be developed and to be provided to users geometrically increases and the lifetime of services is shortened requiring services to be developed within a short period. To support the market demand for a massive service delivery, the IPTV platform based on service delivery platform (SDP) is essential. The SDP is a technique developed to meet the variation in communication and information technology convergence environments, allows service providers to rapidly create and deliver convergence services. This paper describes an Open IPTV service delivery platform structure and method for supporting rapid service creation by reusing pre-defined IPTV service components. We describe key components and functionalities of SDP, IPTV Enablers and its combination for service convergence. We show customer targeted mobile advertisement for Open IPTV convergence service example.**

***Keyword*— IPTV, SDP, SOA, ACAP, Open IPTV Platform**

I. INTRODUCTION

The main environmental change brought on by digital broadcasting such as IPTV, Smart TV and digital cable TV is an advent of a bi-directional broadcasting business that uses a telecommunication return channel. This is a change from 'TV as a medium of transaction', which is one way watching of analogue TV, to 'TV as a marketplace', which connects the viewer directly, collects the viewer's opinion bi-directionally, and reapplies the viewer's reaction to service. Figure 1 shows various examples of bi-directional convergence services combining broadcasting, telecommunication and related information [1, 2, and 3].

Using those bi-directional characteristic, IPTV provides various kinds of convergence service such as information providing, advertisement, and e-commerce. But development of new convergence service is difficult because most of IPTV broadcasting system in Korea uses ACAP (Advanced Common Application Platform) as a base middleware platform [4]. The ACAP API has different shape according to IPTV service providers. General Service developer cannot easily develop those telco-dependent ACAP applications.

The characteristic of IPTV convergence service is a dependency with broadcasting content. The convergence services provided during channel service are tightly coupled with the contents of channel service. For example, channel content related information is shown on TV for the information providing service. For the advertisement, content related advertisements are selected and shown on TV.

Fig. 1. Example of IPTV convergence service

The number of services required to be developed and to be provided to users geometrically increases and the lifetime of services is shortened requiring services to be developed within a short period. Furthermore, with the rapid development of information technology such as web technology, there is a need to integrate information, communication and broadcasting technologies to create new convergence services. Moreover, users want to receive services only for themselves and act not only as service consumers but also service prosumers with the spread of various personal devices. [5] The ACAP is not sufficient to support those requirements.

In the enterprise domain, the SOA (Service Oriented Architecture) has been used for integrating various kinds of business services. In SOA, systems are divided into basic service components. These services are distinct units that can be independently reusable. The Service Delivery Platform (SDP) is one of implementations of the SOA concept in an enterprise domain [6].

A service delivery platform (SDP) is a technique developed to meet this variation in communication and information technology environments, allows common carriers to rapidly create and deliver services efficiently to provide the services and assists third party service providers or personal

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information providers in efficiently participating in service business. [5, 6]

Conventional techniques relating to the SDP mostly define the SDP as a set of enablers corresponding to abstract forms of physical devices of a network or the Internet. These conventional techniques provide general SDP structures in which service common functions such as an operation support system (OSS)/business support system (BSS) are connected with the enablers of the SDP to enable rapid service creation and third party service providers and users can abstract functions to create and provide services even if the third party service providers and the users are not network operators. [7, 8, 9]

Fig.2. Major characteristics of SDP

This paper describes an Open IPTV service delivery platform structure and method for supporting circumstances in which users can be a service provider. We describe key components and functionalities of SDP, IPTV Enablers and its combination for service convergence. We show customer targeted mobile advertisement for Open IPTV convergence service example.

II. KEY COMPONENTS OF SDP

A. Common BUS

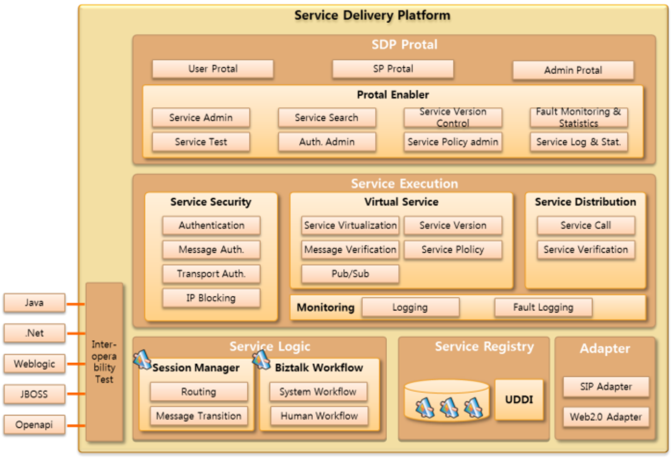

Fig.3. Architecture of SDP

Figure 3 is a common architecture of SDP providing convergence services. The concept of SDP consists of two parts: Common BUS and Enablers. The Common BUS is an execution environment of Web services and web service directories. The common BUS has a similar role with that of the Enterprise Service Bus (ESB). The ESB is a mediating hub at the time of Web Service coordination. It acts as a message broker between services. When an application tries to find Web Service in its routine, ESB finds the appropriate Web Service with application's context.

B. Enablers

The original concept of enablers came from Open Mobile Alliance (OMA). The enablers are the function that abstracts network functions and provides them to third party application developers through application programming interface (API). Enablers interact with each other and create other services. The OMA does not specify a protocol for the interfaces of enablers or a specific mechanism for combining these enablers. [6] Enabler is a building block that encapsulates reusable functionality.

We used Web services specification for the implementation of enablers. Web Service Description Language (WSDL) is used to describe the interface of services provided by enablers. Simple Object Access Protocol (SOAP) protocol is used to communicate between services.

C. Server Configuration

Figure 4 shows SDP server configuration. The virtual service and service distribution will be explained at chapter III. The Session Manager is used to create a new session in SDP. The service creation environment is used for making convergence service primary scenario. It provides graphical user interface to drag and drop service enabler functions to make the scenario. Service registry saves service information and portal server reveals the interface of service enablers to be used to make convergence service.

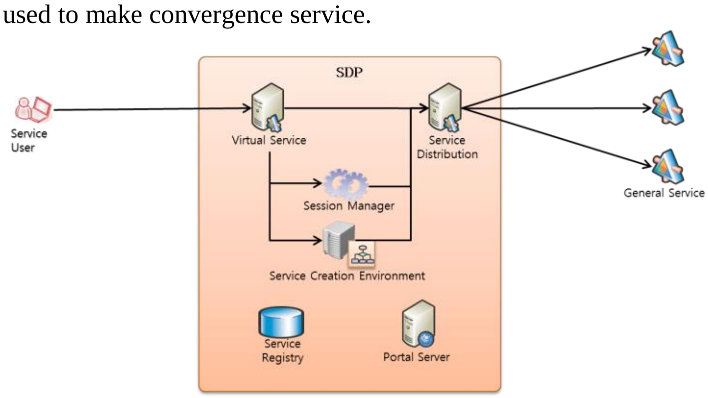

Fig.4. SDP server configuration

III. KEY FUNCTIONALITIES OF SDP

A. Service Virtualization

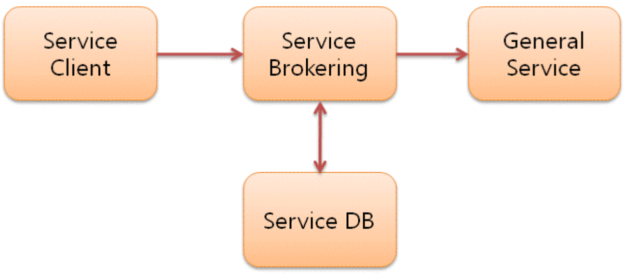

Fig.5. Concept of Service Virtualization

Service virtualization is a recent trend of SOA focusing on providing common infrastructure to create and manage complex service eco-system. By using service virtualization, service developer can focus on service feature developing without worrying on how functions are provided, consumed, and managed.

Service virtualization does not modify general service code, rather makes virtual service providing the API functions before executing service. The key idea of service virtualization is service brokering residing between service client and service implementation.

Service brokering is needed for a separation of client and general service. In this architecture, client cannot connect directly with general service. It can only communicate through brokering service. At the position of service brokering, virtualized service is hosted and exported to service user.

Service broker reads information for DB and decides how to host virtualized service. This approach exports several virtualized service for one general service, we can adopt easily to various customer scenarios.

All communications are transmitted through service broker. We can provide various kinds of brokering services: version control, protocol transfer, monitoring, and real time policy decision. Service virtualization does not change client and general service code.

Service virtualization has several advantages. It provides independent ownership of SOA's each layer. For example, service provider develops service interfaces and logics. Operator describes endpoint policy and message standards. Architect professionals define service level policy and execution patterns. Business owner describes business policy and requirements. All of above can cooperate at the centre points.

Eventually, service virtualization reduces time-to-market for a new service and provides more flexible and substantial methods for managing service environment.

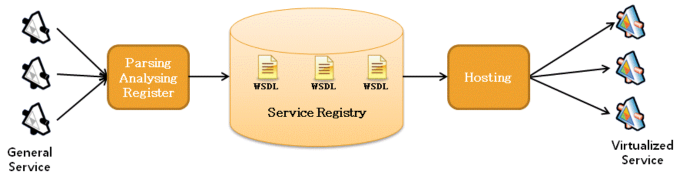

Fig.6. Architecture of Service Virtualization

Figure 6 shows implementation model of service virtualization. It parses general service's WSDL, analyses information, and then registers into service registry.

B. Location Transparency

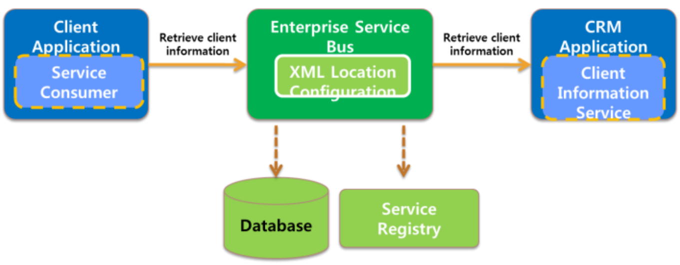

Fig.7. Concept of Location Transparency

For a client, there must be no distinction between the usage of local and remote SOA services. They should be accessed in the same manner as if they were present in the local SOA framework. To provide location transparency, the SDP manages service location at registry and mediate it. With this feature, service execution is not affected by the change of service location.

C. Service Authorization

The SDP service delivery control function assists managing and selling of the value-added services. Delivery control may include user and partner authentication, authorization, credit control, and SLA enforcement. [12]

For services requiring a user limitation, certification is granted an access to only authorized users. Also the SDP authorization function provides WS-Security standard that is Web service authentication capability

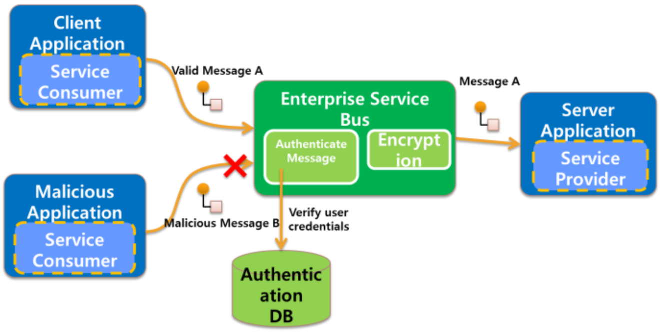

Fig.8. Concept of Service Authorization

D. Service Protocol Conversion

To easy the creation of convergence service, an ESB used as a transitional gateway to convert protocols. Today with introduction of WEB 2.0, there are a lot of de-fecto standard protocol like XML/HTTP RPC, REST,JSON etc. Sometimes SOA systems have to support these kinds of protocols. The generic proxy pattern provides a protocol converter.

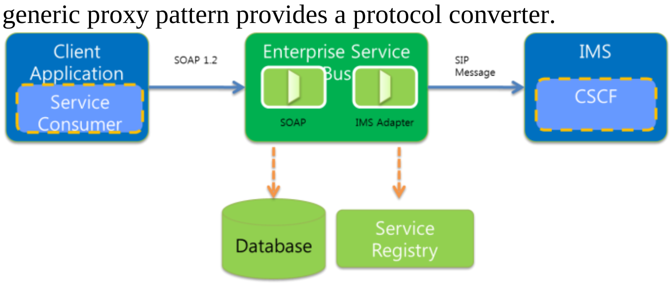

Fig.9. Concept of Service Protocol Translation

There are several types of proxy listed below: [13]

- Edge Proxy (Inbound): This is entry point of our ESB. It covers protocol conversion to internal SOA protocol. (Web services)
- Common Proxy: This is point to handle cross cutting concerns for system authorization, authentication, logging, billing etc. And route the service request to appropriate local proxy.
- Local Proxy: It is one-to-one mapping to Business service. It can just forward request to business service or it contains mediation logics. (Intermediary logic – Transformation, Routing, Function adding, etc.)
- Edge Proxy (Outbound/Optional): This proxy is another edge proxy for outbound protocol conversion. This is optional. In our architecture internal protocols are integrated with web service. This proxy is used for legacy integration.

E. Message Format Conversion

Along with the protocol conversion, the message format conversion is needed because the number and types of arguments are different.

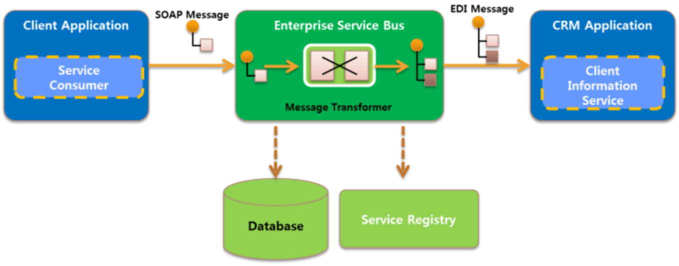

Fig.10. Concept of Message Format Change

F. Message Routing

Based on the type of individual message, the message routing function sends the message to one of the many services available out-of-the-box on the platform.

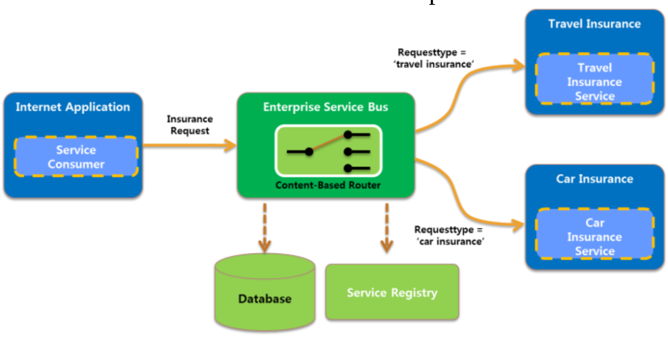

Fig.11. Concept of Message Routing

G. Monitoring

Service delivery platform should have total functions to create, manage, and providing convergence service. The monitoring function is mandatory for managing and provisioning of convergence services.

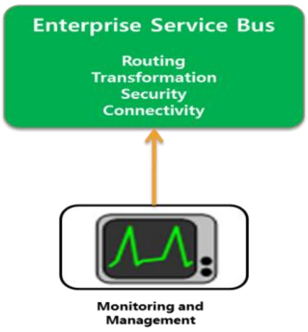

Fig.12. Concept of Monitoring

IV. Open IPTV Platform

IPTV is defined as multimedia services such as television /video/audio/text/graphics/data delivered over IP based networks managed to provide the required level of QoS/QoE, security, interactivity and reliability by ITU-T Focus Group.

If we focus convergence, we can define IPTV as multimedia services delivered over IP based wire & wireless converged networks managed to provide the required level of QoS/QoE, security, interactivity, reliability and openness, and for any contents to be optimally consumed and generated by users anywhere, anytime, and with any device.

The main features of IPTV are bi-directionality and openness. IPTV platform has an importance to support these features.

We developed open IPTV platform with four characteristics: openness, personalization, convergence and prosumer support. The Open IPTV platform is prosumer concept next generation platform technology that anyone can easily create, process and edit services.

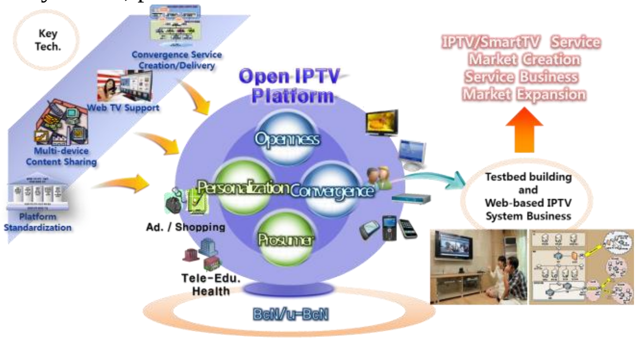

Fig.13. Concept of Open IPTV Platform

Typically, IPTV platform means middleware. The IPTV middleware uses client/server architecture and the client often resides at the STB. The middleware controls the customer interaction with the service and, therefore, plays a very important role in controlling the customer's overall experience. The definition of IPTV middleware is a layer of software between applications and resources, which consists of a set of service enablers that allow multiple functionalities running on one or more devices in an IPTV system to interact across a network. Figure 14 shows a concept of IPTV middleware.

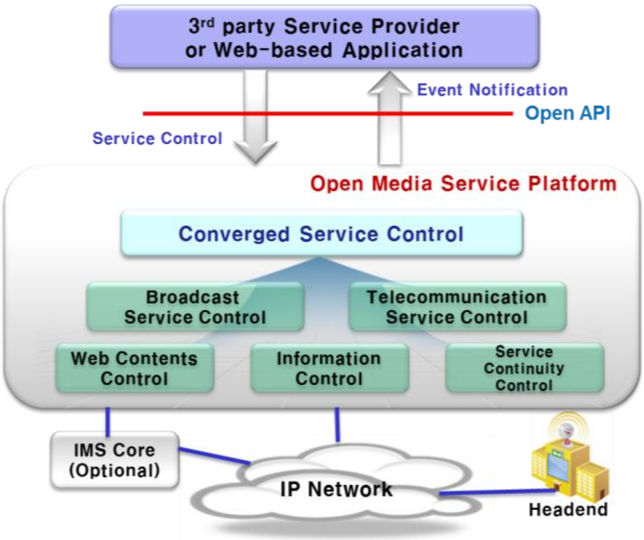

Fig.14. IPTV middleware concept

IPTV middleware also defines and manages subscribers, the services available to them, the business rules and the billable transactions associated with their use of the system. It also oversees or directly manages content assets, physical assets, and to an extent, oversees and manages many of the subsystems of the end-to-end IPTV deployment ecosystem. As such, it is extremely complex, not to mention the fact that the operators deploying it are generally not familiar with some of its core enabling technologies, nor with the services it enables.

Previously, when only wired and wireless telephones existed in the communication environment, network operators or service providers generated and provided services, and the number of generated services was small. A collective system for executing a service, such as a service providing system or a service/user management system was constructed for the service whenever needed. [11]

In the current service environment in which circuit-based communication is changing to Internet-centric packet-based communication and into which wired and wireless communications are integrated, the number of services required to be developed and provided to users geometrically increases and the lifespan of services is shortened to allow for services being developed within a short period. Furthermore, with the rapid development of information technology such as web technology, there is a need to integrate information, communication and broadcasting technologies to create new convergence services. Moreover, users want to receive services only for themselves and act not only as service consumers but also service prosumers with the growing popularity of various personal devices. [11]

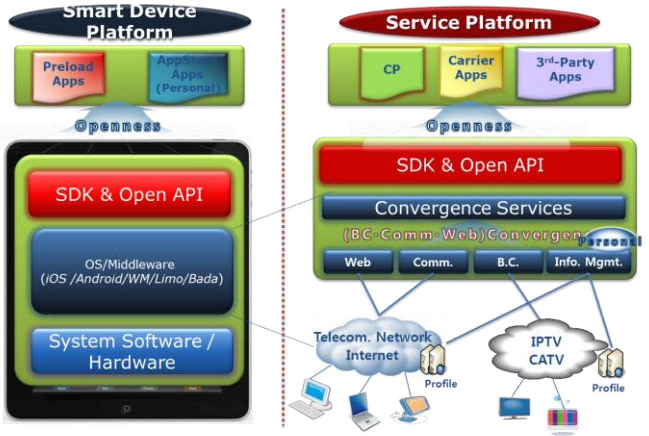

Fig.15. Comparison with Smart Device platform and Service Platform

To meet these changing environments, there are several attempts to include service platform technologies into IPTV such as Open API and SDP (Service Delivery Platform).

The Platform makes it possible to develop services network provider independently. It shortens the development period by recycling existing services, which makes it easy to develop various convergence and personalized services. The shorter development time gives CAPEX/OPEX (Capital Expenditure, Operational Expenses) advantages to service provider: fast commercialization, extending business opportunities.

Sometimes, we confuse the service platform to device platform. The device platform has SDK and Open API to execute applications in device. The SDK has libraries and interfaces for OS and applications shown in figure 15.

The service platform resides in server not in terminal device providing service components and interfaces.

Figure 16 shows Open IPTV platform SDP enablers. It has hierarchical structure. At the very low level of the platform, network support enablers control network capability according to service request such as bandwidth.

Primitive service enablers are grouped as broadcast control, telecommunication service control, web content control, and information control. In each group, unit enablers are defined that has an atomic function. Combining these unit enablers, the platform consist convergence service control group layer. The combined enablers defined in highest layer looks like service. The application server (AS) executes customer service that calls platform enablers as a reusable function.

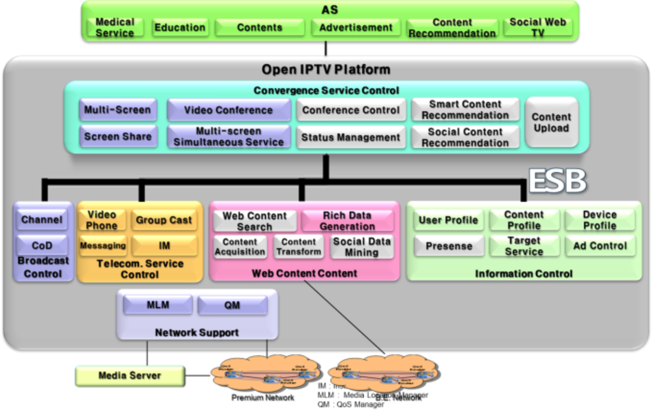

Fig.16. IPTV platform Enablers

Figure 17 shows how the IPTV service reuses platform enablers. For example, telemedicine service uses group casting, messaging, CoD, presence, and video phone primitive enablers. And it uses screen sharing, simultaneous viewing, conference screen sharing, and conference simultaneous viewing convergence enablers.

Other services such as distance education and smart work shares defined enablers of IPTV platform.

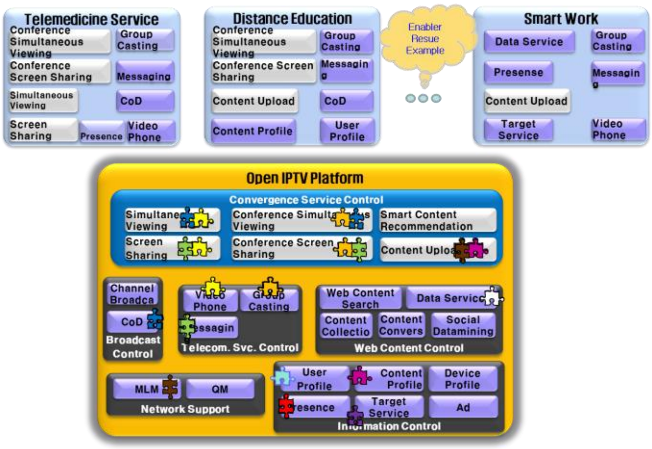

Fig.17. Reuse of Enablers

Figure 18 shows service enabler hierarchy. The primitive service enablers are composed of unit functions, which can be used for creating convergence service shown as grey box in figure 18. For example, service C uses function 1, 2, and 5 in CoD (Contents on Demand) enabler.

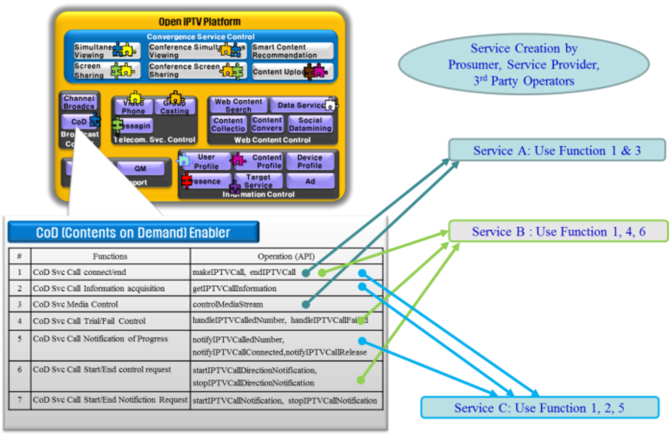

Fig.18. Service Enabler Hierarchy

Figure 19 shows targeted advertisement service created using IPTV platform. While customer are watching VOD or real-time channel service, advertisement is sent to user's smartphone that is prepared according to contents and customer properties such as VOD's actor, user's sex, age, etc.

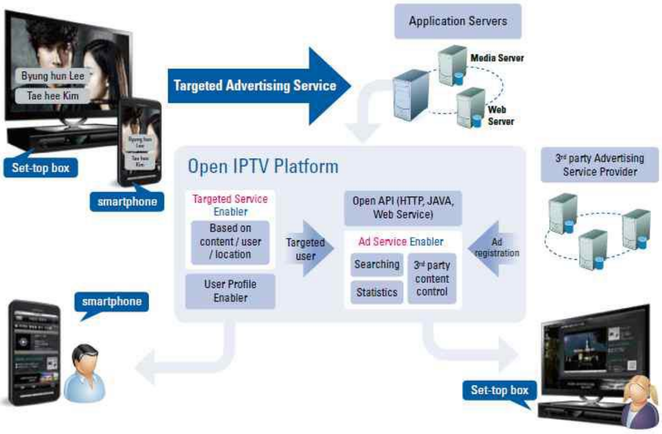

Fig.19. Tatgeted advertisement service

The split EPG terminal has a function controlling IPTV service via home AP. A mobile user watches golf sports channel in VOD service. He already gave his preferences to the profile enabler via open service platform. For instance, since the profile enabler knows that he enjoys golf as outdoor sports, when he detects golf driver on watching golf contents, the mobile advertisement process enabler may give him advertisement moving picture about newly released golf driver. Mobile advertisement process enabler may give helpful information to him as well as connect to the purchase step by the mobile device.

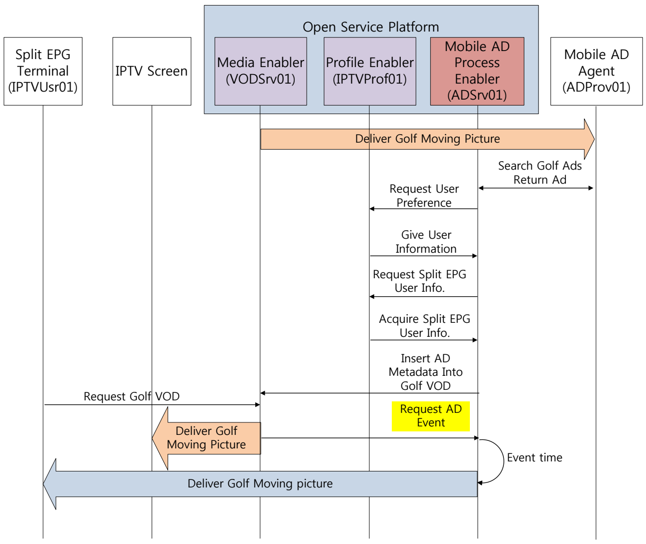

Fig.20. Service flows of Targeted Advertising Service

Fig. 20 shows example of targeted advertisement service using SDP. Mobile advertisement agent may be person or sub-system of an advertisement service provider. He also watches a golf VOD service via media enabler within open service platform. The mobile advertisement process enabler searches a golf advertisement among many advertisement contents of a mobile advertisement agent. That golf advertisement is related with revealed product in golf moving picture. The mobile advertisement process enabler acquires user preference and check if mobile users own split EPG terminals. The convergence enabler then inserts advertisement metadata into golf VOD. A mobile user with split EPG terminal requests to view golf contents to open service platform. As soon as golf moving picture is delivered to an IPTV user, advertisement request event is generated.

We made other convergence service combining web API and personal data.

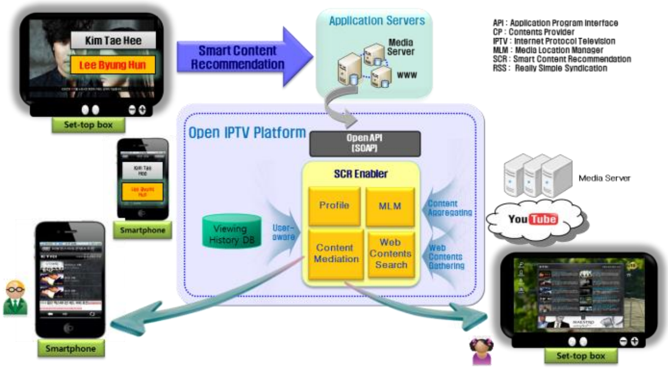

Fig.21. Smart Content Recommendation Service

Figure 21 shows smart content recommendation service that recommends related content based on user's personal history. For the content generation, the enablers search web space in real-time based on Web open API. The platform automatically aware the device used, then provide appropriate contents according to the device's capability such as CPU clock speed, screen size, etc.

The SDP has service creation environment (SCE) shown on figure 22. The SCE has graphical user interface that makes it possible to edit convergence services using service components. It also has a creation function of composite component combining unit components.

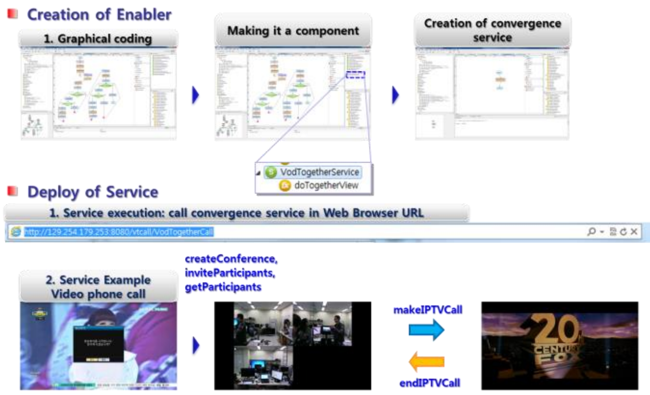

Fig.22. Service creation environment and deploy of service

V. CONCLUSIONS

Service Delivery Platform (SDP) used for a creation and management of convergence services. Service virtualization is a key concept of SDP for a service convergence because it provides service feature independence among unit services (components) of convergence services.

Service provider can create service components using standard interface without worrying how to integrate each unit services. After creation of service components, the service provider can create convergence service combining those reusable components. Using the SDP's feature, the efforts of service creation can be reduced more than half.

The easy service creation feature will brought a business market chance: creating various business models such as prosumers, service provider, hosting provider, MVNO, and Telco shown in figure 23.

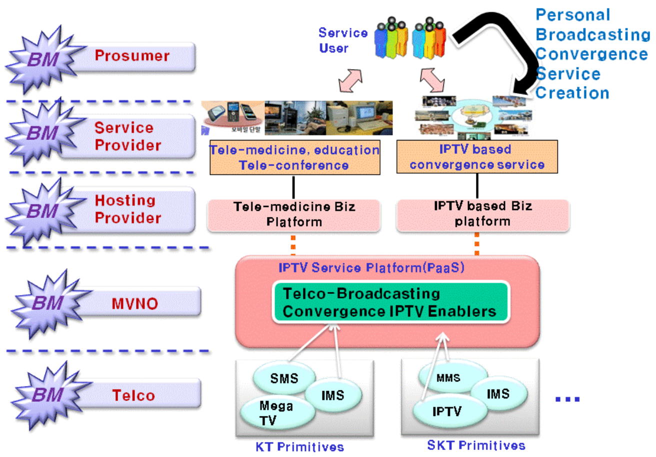

Fig.23. Business model brought by using SDP

IPTV service is an example of convergence service between telecommunication and broadcasting services. SDP will have an essential role on convergence service creation and management because of its SOA concepts.

We developed several service component groups for SDP based IPTV service platform such as broadcasting service control, telecommunication service control, web contents control, network support, and information control. For example, the telecommunication service control components group consists of video telephone, group casting, messaging. With those components, IPTV service provider can create convergence IPTV service providing telephone call notice or PIP video-phone screen while watching channel broadcasting.

Using open platform, we can make social service by making social service components shown in figure 24.

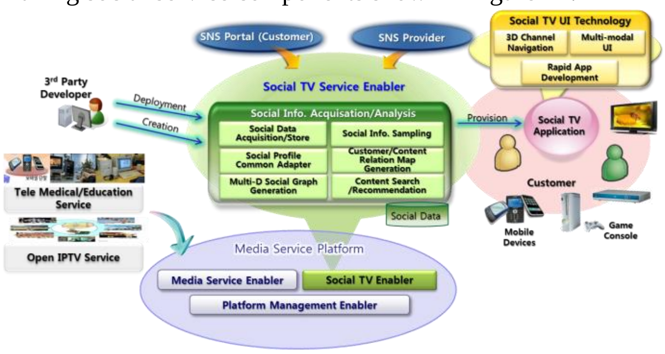

Fig.24. Social service enablers

The SDP expected to be a key part for M2M (Machine to machine) or IoT (Internet of Things) service platform because of its easy way of creating convergence services.

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Structure Safety Inspection System Using Multiple Sensors and PTZ Camera

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***Abstract*—In recent years, those aging buildings such as the high-rise buildings and the chemical plant structures generate many social and economic issues due to crack, fire and collapse. Furthermore, these social and economic issues will lead to national loss. The aforementioned problems cannot be resolved through human eye or human power. This thesis proposes the structure safety inspection system using a small aircraft equipped with multiple sensors in order to address these problems. This small aircraft saves and manages the data obtained through the structure inspection and also provides efficient information. The purposes of this thesis are to synchronize, save and manage multiple sensor data, video and thermos graphical data that are transmitted from a small aircraft and also to implement the safety inspection integrated management system that provides inspection results and history information.**

***Keyword*— Multi-Sensor, Small Flying Vehicles, Sensor Fusion, Monitoring System, PTZ**

I. INTRODUCTION

Recently, as outdated high-rise buildings, bridge piers, wind power generators, petro-chemical plant structures are deteriorated, a lot of problems for the dangerous situation such as internal/external cracking, fire and disasters are taken place and create a social issue. In order to detect dangerous situations and cracking, there is a small flying vehicle that does the work that is hard to be inspected by the workers as a proxy. This small flying vehicle mounted with various sensors provides a function of integrated management services from structure monitoring to safety inspection. A process of developing small flying vehicle and verifying its performance for safety inspection of structures is continuity of complicated process from its design to test flight and a lot of cost and research time are required. In order to perform safety inspection for the structures, mounted various sensors are required to be measured and measured result is required to be transmitted. This study intends to suggest efficient wireless transmission, control technique for sensor data including sensing space of sensed data, data accumulation and its transmission.

This study intends to design integrated management system for safety test that stores and controls multiple sensor data, image, thermal infrared image, and data being transmitted from small flying vehicle through its synchronization and provides test result and historical data information.

II. PROCEDURE FOR PAPER SUBMISSION

Various sensors, imaging equipment and communication equipment are mounted on unmanned small flying vehicle. Data obtained from mounted various sensors and devices will be controlled and information provision service will be researched [1,2].

A. Review Stage Type of sensor

TABLE 1. Kinds of sensors

		
CO Sensor	VOC Sensor	Dust Sensor
		
Ozone Sensor	CO2 Sensor	Humidity sensor

Temperature sensor is a device used for recording or controlling temperature by detecting temperature of fluid such as air or water or wall. Detected temperature is converted to electric signal and transmitted [3].

Humidity sensor is a device that detects humidity and outputs such humidity as electric signal. This sensor uses a mechanism that electric resistance and its capacity of porous ceramics and polymer electrolyte are changed due to physical absorption of moisture.

CO sensor is a sensor used for detecting carbon monoxide. In our living environment, dangerous gases of numerous types exist and recently, gas-related accident in ordinary homes, business places and construction sites, explosion accident in petrochemical combine, mines, chemical plants and pollution,

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contamination are taken place in a row. As it is almost impossible for human sensory system to quantify concentration of dangerous gas or discriminate its type, gas sensor that uses physical, chemical properties of substances is used for detecting gas leakage, measuring its concentration and warning dangerous situation.

CO_2 sensor is a device for measuring carbon dioxide. Most common principle of CO_2 sensor is NDIR and chemical gas sensor. Measuring carbon dioxide is important for monitoring indoor air quality and various industrial processes.

Ozone sensor is a device for measuring ozone concentration in atmosphere. Dust sensor is a device for detecting floating dust or number of condensation nucleus.

VOC sensor is a device for evaluating air quality based on the amount of volatile organic compounds –cigarette smoke, harmful smoke and odour being generated at the time of cooking, outside pollution source, pollution source of living organisms [4].

B. Final Stage Structures that require safety test by small flying vehicle

TABLE 2. Diversified structures that require safety test

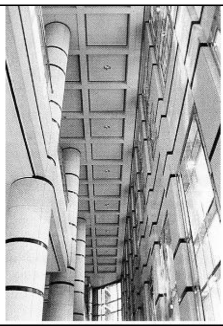
	
a. High-rise building	b. Building inside
	
c. High smoke stack	d. Chemical plant
	
f. Cultural property	g. Wind power generator

Table 2 is an illustration of diversified structures [5]. a. At the time of constructing high-rise building, safety problem is required to be inspected and for outdated high-rise buildings, efficiency of service life extension is provided by detecting cracking and abnormal temperature by its deterioration, b. By detecting cracks of building inside, building safety is increased, c. By monitoring cracking and dangerous elements of cultural property, national waste could be reduced. Recently, due to frequent fire in chemical plants, safety is required in reality, d. f. By analysing, investigating cracking and emission gas in internal/external walls of plant smoke stack and chemical plants in real time, an advantage of being able to prevent an accident in advance is provided. In addition, site application for external cracks inspection through cinematography and internal cracks inspection through thermal infrared camera for the blades and tower of wind power generator that is popular as a renewable energy source will be performed and safety inspection manual for wind power generator is under the process of R & D.

C. PTZ(Pan Tilt, Zoom) Camera

Format and save your graphic images using a suitable graphics processing program that will allow you to create the images as PostScript (PS), Encapsulated PostScript (EPS), or Tagged Image File Format (TIFF), sizes them, and adjusts the resolution settings. If you created your source files in one of the following you will be able to submit the graphics without converting to a PS, EPS, or TIFF file: Microsoft Word, Microsoft PowerPoint, Microsoft Excel, or Portable Document Format (PDF). GWP is a scale of evaluating how much heating effect of gas of 1kg is for a certain period of time after greenhouse gas is emitted in the atmosphere when comparing it with carbon dioxide of 1kg. In case of assuming CO_2 as 1 based on 100 years, CH_4 is 21, NO_2 310, HFCs 1,300, PFCs 7,000 and SF_6 23,900, respectively [3]. The location information of camera consists of the coordinates to represent the current location of moving objects and structures, the coordinates to represent the location of camera and the distance, height difference and angle between the objects.

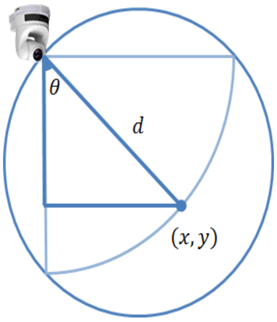


Fig. 1. Location Information of Camera

Fig. 1 is the location information of camera.

The location information of an object consists of the coordinates to represent the current location of a moving object, the coordinates to represent the location of a camera and the distance, height difference and angle between the objects. The location value of camera will not be changed once it is installed. The location of a moving object continues to change; thus, the distance, height difference and angle value between a camera and a moving object shall be calculated based on the pre-defined formula for the two coordinates.

The moving object (x, y) and angle determines the horizontal rotational direction (θ) of a camera, whereas the distance (d) between objects determines the enlargement and reduction magnification of a camera. In addition, the height difference of a camera determines the vertical rotational angle of a camera [6].

It is required to control the operation of horizontal rotational angle, the vertical rotational angle and the enlargement/reduction value for PTZ camera. [7]

The operation signal of a camera requires a conversion between those coordinates and Cartesian coordinates. It is also necessary to have the coordinates (M_x, M_y) of a moving object calculated on the orthogonal coordinate plane and the location coordinates of a camera (C_x, C_y). It is possible to obtain the distance difference between two points d_{xy} through Formula (1) by utilizing the two coordinates.

(1) $d_{xy} = \sqrt{d_x^2 + d_y^2}\ ,\ d_x = |M_x - C_x|\ ,\ d_y = |M_y - C_y|$

It is required to calculate the horizontal rotational angle of 360 by using Formula (2) for 360 degree system by converting the reference coordinates into the polar coordinates that uses the location coordinates of a camera as the starting point.

$$\theta_p = \begin{cases} \tan^{-1}(\frac{Y}{X}) & X > 0,\ Y \geq 0 \\ \tan^{-1}(\frac{Y}{X}) + 360^\circ & X > 0,\ Y < 0 \\ \tan^{-1}(\frac{Y}{X}) + 180^\circ & X < 0 \\ 180^\circ & X = 0,\ Y > 0 \\ 270^\circ & X = 0,\ Y < 0 \end{cases} \quad (2)$$

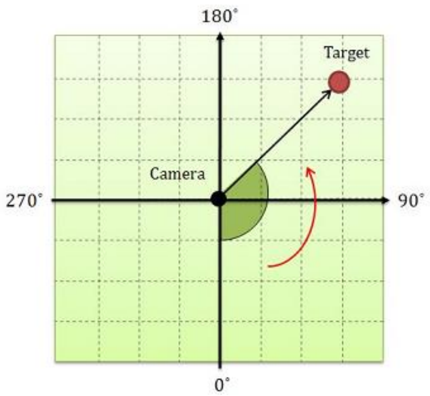


Fig. 2. Scope of horizontal rotation

The scope of horizontal rotational angle θ_p of a camera is $0^\circ \leq \theta_p \leq 360^\circ$.

As for the vertical rotational angle of a camera θ_t, the height relative to the surface from the installation point of a camera is h_c, whereas the height of a moving object is h_m. They can be obtained through Formula (3).

$$\theta_t = \cos^{-1}\left(\frac{h}{\sqrt{d_{xy}^2 + h^2}}\right),\ h = |h_c - h_m| \quad (3)$$

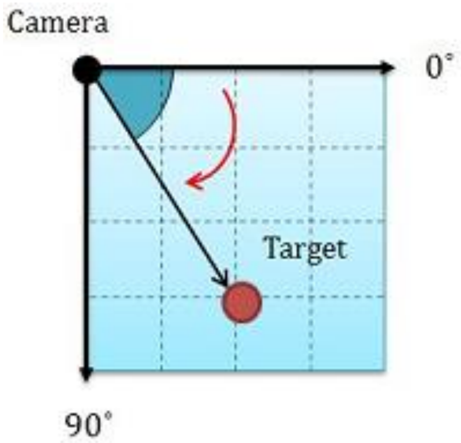


Fig 3. Scope of vertical rotation

The scope that the vertical rotational angle θ_t of a camera can have is $0^\circ \leq \theta_t \leq 90^\circ$.

The reliability of operation control value of PTZ camera for the operation control of a camera will increase with a higher degree of accuracy for the process of obtaining the location of an object.

III. Contents and Method of Study

There are various sizes, heights and shapes in relation to the structures. It is difficult for a small aircraft to approach at short ranges in terms of detecting crack or risk factors when accessing to a structure. PTZ camera is useful as a camera to be installed on a small aircraft to detect the location of cracks in a structure because it can be enlarged and also it is able to move to left and right. Moreover, such functions of PTZ camera as pan, tilt and zoom can be utilized in order to detect crack and risk factors when a subject is at a remote location.

A. *PTZ Module of Video Camera*

It is possible to examine in more detail a structure by conducting PTZ control of a video camera in order to conduct visual inspection of a structure that is hard to access from a short distance.

It is possible to shoot a structure in a wide area with 355° at left and right and 120° at top and bottom of PTZ camera. It is also possible to recognize an object at up to 30M in dark nature or at night with the function of IR camera.

The screen of PTZ camera is set at 200 million pixels. The problem associated with blind spot when conducting horizontal and vertical rotation and enlargement/reduction operation can be solved.

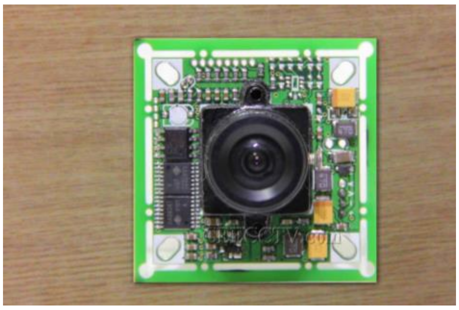


Fig. 3. PTZ camera of video camera

Fig. 3. shows PTZ camera that is able to detect high-rise buildings and places that cannot be detected by human eyes because it is equipped with a small aircraft.

Fig. 4. Small aircraft equipped with multiple sensors

Fig. 4. Shows a small aircraft equipped with multiple

sensors. It examines the safety inside and outside a structure through multiple sensors and video sensors.

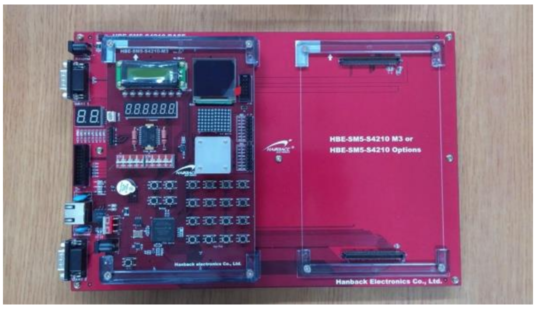


Fig. 5. Multiple sensor module embedded system

Fig. 5. is the embedded module that processes and analyses the sensors of various types installed in a small aircraft. Currently, the research project that focuses on the transmission protocol and sensor data monitoring system to receive various signals is in progress based on the embedded system to receive the signals of sensors. At present, it is the monitoring system that measure carbon dioxide in the air using CO2 sensor and sends signals when the amount and proportion of carbon dioxide are high.

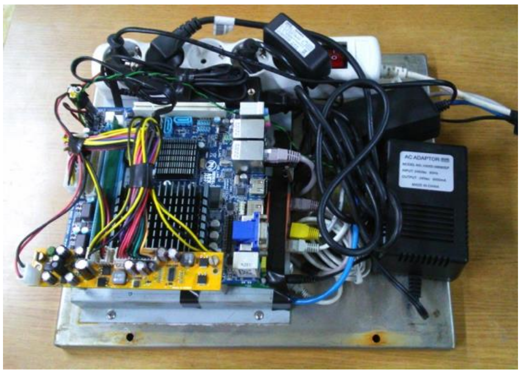


Fig. 6. Structure safety inspection integrated management system based on a small aircraft

Fig. 6. shows the structure safety inspection integrated management system based on a small aircraft. It consists of power supply unit, web server and Wi-Fi based wireless video transmission system to perform the function of storage server.

It is the low-power video management server system based on an embedded system that combines, saves and manages multiple sensors and PTZ camera. As for videos, those videos transmitted in motion JPEG encoding are synchronized in accordance with the time. Upon request of users, the sensing data and videos are also synchronized and transmitted.

B. *Design of multiple monitoring system*

Multiple sensor monitoring system is a system for preventing occurrence of cracking and various dangerous situations due to diversified causes including deterioration or defective work of structures in advance. In addition, this system inspects data in the air in real time using unmanned flying vehicle and by using obtained data, monitors subject structure in real time.

Multiple sensor monitoring system is mainly divided into small flying vehicle and embedded system. Small flying vehicle is an unmanned flight system that performs data detection and transmission in real time by using multiple sensor and embedded system receives data transmitted from small flying vehicle and processes received data in real time and at the time of risk occurrence, informs users of dangerous situation through smart phone.

As embedded system that is data processing system is required to process data collected by heterogeneous multiple sensors based on processing module that may process data in real time with high speed and perform a function of processing images in real time at the same time, it was designed based on excellent performance. In addition, as sensors being used for multiple sensor monitoring system use diversified sensors including PTZ camera having a function of infrared ray, temperature, humidity sensors, it is required to use and provide diversified interfaces.

Embedded system provides a function of acquiring, processing and transmitting various sensor data and controlling sensors by analysing instructions after receiving it and provides monitoring information of sensors so that status information of each sensor could be observed remotely. At the same time, in order to synchronize data collected by each sensor, it provides a separate function and a process of storage, transmission processing of sensor data is required.

C. *Structure of Multiple Sensor Monitoring System*

The whole configuration diagram of the system proposed in this paper is shown on figure 7.

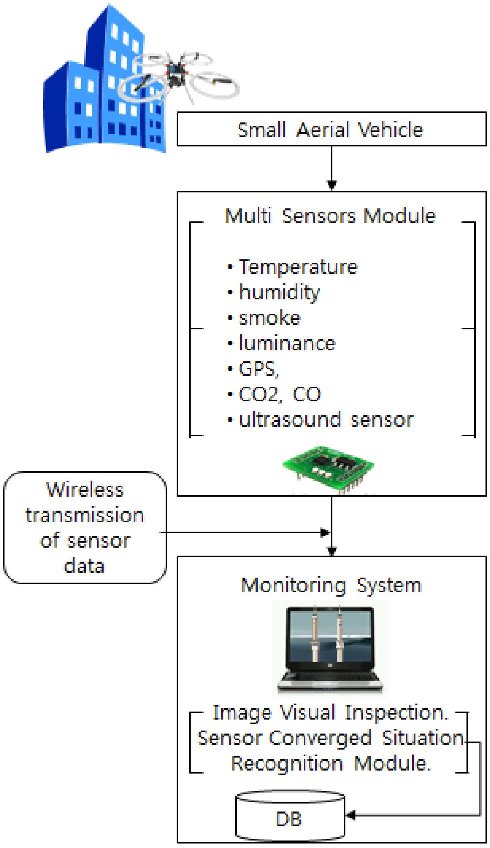


Fig. 7. System Configuration Diagram

As main function of multiple sensor monitoring system is that the functions such as high speed input/output processing of various sensors, real time synchronization of sensing data, transmission of processed data are required to be performed at the same time, real time monitoring is required. By flight of small flying vehicle, each sensor starts to be operated and at this time, storage of sensing data and its transmission module are required. In addition, this system was designed to transmit and store collected data in big data storage device and process stored data after the flight is finished.

Each module of multiple sensor monitoring system was designed to perform each function that is required to be provided by data processing system. In order to process image data of PTZ camera, compression module is provided and for data synchronization of various sensors, synchronized module and transmission module for transmitting data in real time are provided. In addition, in order to process input/output of diversified sensors being connected through each interface, temporary storage space was provided. These modules provide informing and monitoring system function through smart phone by it being implemented in parallel.

IV. SENSOR CONTROL AND DATA PROCESSING

A. Sensor Control

Multiple sensor monitoring system provides real time control function to multiple sensors. As this system uses operating small flying vehicle and commanding embedded system, multiple sensor monitoring system provides control function to diversified sensors. This system controls sensors by transmitting instructions to sensor that is desired to be controlled and using data processing system that analyses transmitted instructions.

B. Data Processing

In multiple sensors monitoring system, sensing data collected by each sensor is processed in real time and transmitted to embedded system. However, as transmission rate of transmission route being used at the time of transmission by embedded system is limited, in order to transmit big data, a process of compressing sensing data is required. In particular, as image data being collected by camera is big data, its compression process is essential and as compressed image data is also unable to be transmitted at one time, it is required to be transmitted to embedded system by dividing it into transmissible packet by using a separate transmission format. In addition, as data of each sensor is required to be transmitted by division at the time of transmitting sensing data, transmission format is required to be indicated with tag matching with each sensor. At the same time, tag of sensing data based on time synchronization is required to be included.

C. Video of PTZ Camera

It is required to fly a small aircraft and transmit the operation of multiple sensors and the data of PTZ camera to the integrated management system. The transmitted data can be verified through the monitor screen. It is possible to confirm the location immediately through GPS sensor and detect the crack and risk factors of a structure.

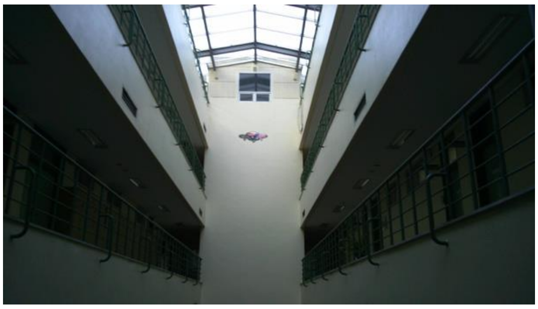
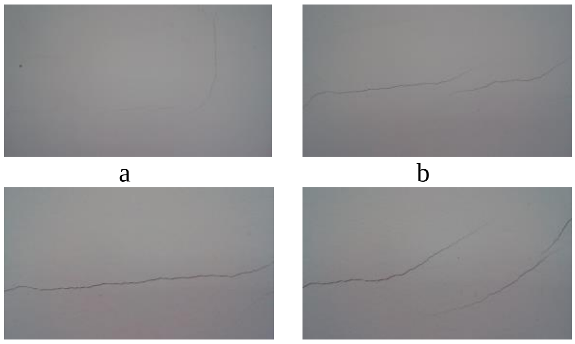


Fig. 8. Structure inspection of small aircraft

Fig. 8. shows how a small aircraft inspects a structure.



a b

c d

Fig. 9. Cracked wall surface taken by a small aircraft

Fig. 9. is the conventional figure taken by PTZ camera of a small aircraft. b is the enlarged version by 2x zoom. c and d are the enlarged versions by 3x zoom. PTZ camera allows us to take pictures of wall surfaces located at a high-rise building and check them accurately and specifically.

V. EXPERIMENTAL RESULT

It is difficult to visually confirm the crack and risk of high rise buildings and high structures. They can be identified using PTZ camera equipped on a small flying object. In the existing method, the person may face with dangerous situation as the person should climb directly to the high rise building. With a small flying object, however, the location of cracks can be safely identified.

The places where the experiment was performed with a small flying object are the inside and outside of building 3 at the department of engineering, Sunchon University. And the experiments were performed 6 times. Even though the video was out of focuses by the shake during video shooting, relatively stable video could be acquired. 4 videos out of 6 were accurate and the location of crack were accurately identified with GIS sensor

Table 3 shows the result of experiment with a small flying object

TABLE 3 result of experiment with a small flying object

Number of experiment	Video acquired	Video accuracy
6 times	4	88%

VI. CONCLUSION

At present, a lot of small flying vehicles are applied, researched and developed in various fields including shooting site of TV program such as entertainment and documentary, patrol purpose for safety control, exploration purpose for roving Mars and other purpose of diversified specificities.

This study is being progressed by using small flying vehicle for safety inspection of structures. By using small flying vehicle for safety inspection of structures, development process that may collect, store, transmit and process multiple sensor data of multiple sensor monitoring system was explained. In multiple sensors monitoring system, modules for high speed input/output processing, real time sensor data synchronization, compression, and transmission of data were designed.

This thesis focused on the use of a small aircraft for the safety inspection of a structure. This thesis described the multiple sensors and PTZ camera for the structure safety inspection. Also, it described the structure safety inspection integrated management system based on a small aircraft, which can collect, save, transmit and process data. As for the multiple sensors monitoring system, such modules as high-speed input/output processing, real-time sensor data synchronization, data compression and transmission were designed.

In the future study, a system that may increase utilization accuracy of various sensors through diversified direct tests by using various sensors and prevent structural cracking and dangerous situations in advance through analysis of image data being transmitted from PTZ and thermal infrared camera is scheduled to be researched.

It is expected that based on this system, various structures would be free from the danger of fire, disaster and deterioration and its high-levelled safety would be maintained with reasonable coast.

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An Adaptive Cooperative Protocol for Multi-Hop Wireless Networks

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Abstract— **A Multi-hop relay communication system has gained tremendous attention recently as it reduces capital investment for expansion of coverage area. In this work, an adaptive cooperative decode-and-forward (DF) protocol was developed to enhance the performance of the system. In particular, a 'best destination relay selection' approach (BDRS) was proposed to achieve high diversity gain. The approach starts by selecting a destination node with the maximum channel gain first, and then selecting a relay node with the minimum outage probability afterwards. Closed-form expressions for the outage probability, which is a measure of system performance, were derived. Their validity was checked by comparing the calculated results with the simulated results from MATLAB software. Both results were found to be almost identical. Simulated outage probability of the proposed protocol was also found to be many folds lower than those of conventional and modified multi-hop communication protocols. Lastly, an optimum power allocation scheme was applied to further minimize outage probability.**

***Keyword*—Cooperative Communications, Multi-hop, Relay Selection, and Routing Strategy.**

I. INTRODUCTION

MULTI-HOP relay communication has become more and more important for the new generation of wireless communication system. It helps expanding service areas, increasing system capacity, and reducing the investment budget for base station expansion. The basic idea of radio relaying [1] is to use a relay node to process base station signal and send them out to another relay or destination node. Multi-hop relaying can expand cell coverage and reduce dead communication spots. Relays can take up some of the traffic load when the full capacity of the base station has been reached. Radio relaying saves the terminal's transmitting power, which in turn prolong battery life.

The relay-based architecture, its cooperation diversity, and cooperative multipath technology have already been implemented worldwide. All of the standards for existing and near future mobile communications systems—e.g., The 3rd Generation Partnership Project (3GPP) [2] and broadband wireless network (IEEE 802.16j) [3]—rely on the concept of relaying. A new project, the Wireless World Initiative New Radio (WINNER) project has planned out in detail an implementation of a ubiquitous broadband mobile radio relaying system.

For a small relaying system of one relay and one destination, there is only one possible route from source to destination. However, in a large relaying network (e.g., wireless sensor network), there are many relays between the source and the destination. A key question is which relay node should be selected to forward the information. One of the relay selection techniques is to simply pick the 'best' of all available relays for two hops and using that relay to decode and forward the information. In [4], the authors present a selection criterion of $\eta_l = \min\left[\left|h_{S,R_l}\right|^2, \left|h_{R_l,D}\right|^2\right]$ and an alternative 'smoothed-out' version of $\eta_l = 2/\left(\frac{1}{\left|h_{S,R_l}\right|^2} + \frac{1}{\left|h_{R_l,D}\right|^2}\right)$, where h_{S,R_l} is the channel impulse response between the source (S) and relay (R_l), $h_{R_l,D}$ is the channel impulse response between relay R_l and destination (D), and $l = 1, 2,..., L$. The relay node with the 'best' channel that produces the highest η_l is selected to retransmit the signal. This selection criterion helps avoid system bottleneck, but it might not be optimum. Another simple way to find a suitable route is by following the conventional protocol. In this protocol, the system selects the best relay that exhibits the maximum received signal to noise ratio (SNR) for each hop on a hop-by-hop basis. Yet, there is a problem with the last hop since there is no alternative route to the final destination. To solve this problem, the authors of [5] proposed an ad-hoc routing strategy–joint selection for the last two hops. We call this technique 'modified conventional multi-hop strategy'. This strategy is easy to implement but its performance can still be improved. We describe it in details in system model B.

In [6], the best relay selection based on the technique of minimum outage route (MOR) was proposed. The authors assumed that each relay node can receive information from the

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nodes of two previous hops and combine their signals using a cooperative protocol. This assumption corresponds to a diversity of two transmitting nodes. The performance of such a system is superior to that of the system described in [5]. Nonetheless, the system performance is still not optimum with respect to the outage probability.

In contrast to the dual-hop transmission in [6], the authors in [7] analyzed transmission by multiple relays, where every relay retransmits the signal from the source to the destination. They found that the outage probability was not reduced by much as the number of relays increased. In fact, in some instances, more relays increased the outage probability. On the one hand, increasing the number of relay nodes increases the possibility that a successful relaying can occur, which increases the mutual information between the source and destination. On the other hand, increasing the number of relay nodes increases the probability of outage condition at the relay and destination nodes. This trade-off is a result of the time-division channel allocation scheme that allows proportionally less time for the source to transmit its signal when the number of relay nodes is increasing, i.e., the source is allowed to transmit only a fraction of $1/(m+1)$ of the time, where m is the number of relays. Hence, an optimal number of relay nodes exists, and it could be determined based on the SNR and channel conditions.

Similar to the model in [7], in [8], the authors investigated a model of two-hop transmission with a cooperative protocol and introduced a strategy of selecting the best relay based on the received SNR and channel quality instead of that of using all relays at a reduced power in [7]. They also derived the model's outage probability. Their result showed a better performance than that of [7]. In [7], the multiple relays could not reduce the outage probability significantly, but the best relay selection in [8] was very different–a larger number of relays resulted in a much higher reduction of outage probability.

In [9], for the purpose of further improvement of the system performance realized in [8], the authors applied a cooperative protocol with Alamouti-coding scheme but still used the best relay selection technique proposed in [8] to their system of two-hop transmission with one source, one destination, and two candidate relays. After the best relay was selected from time to time, four time slots were used to transmit two symbols, following the Alamouti-coding scheme; therefore, the system lost some bandwidth efficiency. To compensate, the authors employed Quadrature Phase Shift Keying (QPSK) modulation. They also derived an expression for the system's outage probability. Their simulation results showed that their system performed better than that in [8] by 1.5 dB at an SNR higher than 20 dB.

In [10], the authors considered a linear network model of a multi-hop relay communication system consisting of a source, a destination, and several relays equipped with multiple antennas. They did not focus on the direct link from the source to the destination within the same cluster. Distributed space-time coding was used to maximize diversity gain. In their discussion, the answer to whether to code a multi-hop relay channel in space or time was that it depends on the available resources such as availability of feedback, decoding complexity, and various requirements of wireless application such as rate, latency, etc.

In this paper, we could not compare our results with those in [10] even though we used a linear network model similar to theirs because their relays were equipped with 2 antennas while ours had only one. Similarly, the cooperative protocol in [6], [7], [8], and [9] could not be compared to ours either because their systems consisted of only two hops while ours consisted of more than two hops, similar to those of [4] and [5]. In reality, multi-hop communication uses many hops and relays in each hop. When a cooperative protocol is applied, there are many candidate relays and candidate destinations in each cluster. There has never been proposed a selection strategy that gives the highest priority to the destination. That was the motivation for this research. Our reason was that the destination of every two hops is the source of the next hop, and we wanted the best source for the next hop, so it was sensible to give the best destination the highest priority. We named our proposed protocol the 'best destination relay selection (BDRS)' approach. We also derived a closed-form expression of the outage probability of our system. To validate it, we compared the calculated results against the simulated ones. We also evaluated our system performance against the modified conventional multi-hop strategy employed in [5]. Finally, we further improved our system performance by employing optimum power allocation for source (S) and relay (R). The results were very interesting. The system tried their best to maintain the S-D link by allocating more power to the source, even when the quality of the transmission link was poor. This finding confirmed that selecting the best destination node first has a tremendous impact on the system's performance.

The rest of this paper is organized as follows: in section II, models of the wireless communication system used in this study is described; in section III, a closed-form outage probability of our system is derived; in section IV, the simulated and calculated results are discussed; in section V, the optimum power allocation scheme and results are discussed; in section VI, the expected real-world implementation issues are considered; and section VII is the conclusion of this paper.

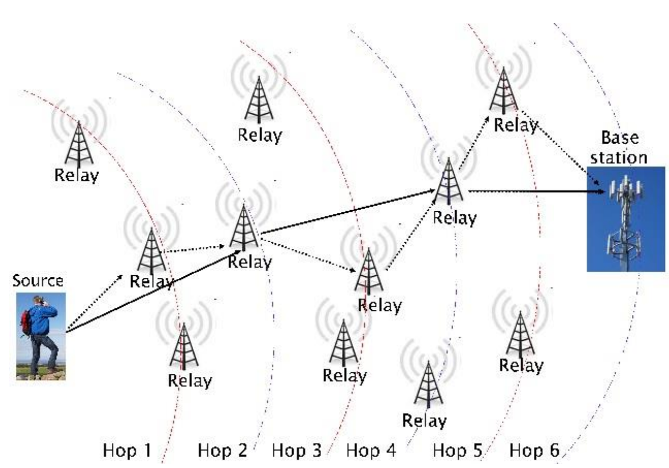


Fig. 1. A multi-hop communication system.

II. System model

In a multi-hop communication where a source node communicates with a destination nose that is out of its coverage area, relays serve the function of a base station by recovering the signal received from the source node and retransmitting it to the desired destination. Hence, relays can reduce the cost of investment of a multi-hop communication system installation. Figure 1 shows a feasible communication area, a number of hops, and an example of a relay selection strategy. In this paper, our system employs a dual-hop relay transmission, in which a cluster of nodes consists of two hops. All nodes in a cluster can receive the transmitted signal from the source node.

In this section, we describe our system model of the conventional multi-hop relay selection approach and the modified conventional multi-hop relay selection approach.

For the sake of simplicity, we depicted an idealized linear network model in Figure 2 with *M* hops, *L* relays, and *L* destinations in each hop [5]. This routing strategy is called an Ad-hoc routing strategy.

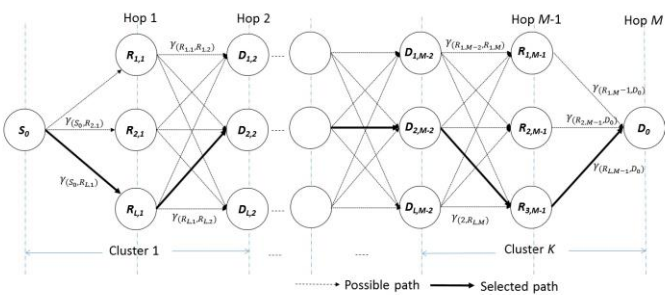


Fig. 2. Idealized linear network model with *M* hops, *L* relays, and *L* destinations for each hop.

In figure 2, it can be seen that there are one source (*S*), one destination (*D*), *M* – 1 hops, *K* clusters, and *L* linearly distributed nodes. A cluster is defined as a combination of one source, *L* relays, and *L* destination nodes for every two consecutive hops, and each node of the linearly distributed nodes functions as either a relay or a destination. The relationship between the index of a cluster (*k*) and the index of

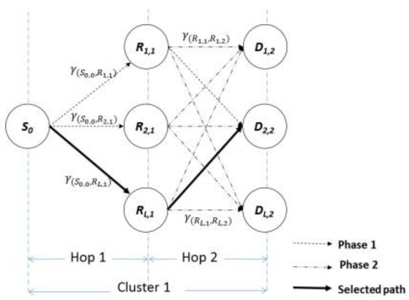


Fig. 3. The first cluster of an idealized linear network model, consisting of 2 consecutive hops, *L* relays, and *L* destinations.

a hop (*m*) is $m = 2k$.

Figure 3 shows an example of a relay selection in the 1st cluster. S_0 is the source node, $R_{l,1}$ represents the relay *l* of the 1st hop, and $D_{1,2}$ represents the destination node *l* of the 2nd hop, where $l = 1, 2,\ldots, L$ and the distances between hops are equal. The channel impulse response of the system is independently and identically distributed. Each node is equipped with one antenna employing a Time Division Multiple Access (TDMA) technique without spatial reuse and a decode-and-forward strategy for signal repeating. A selected relay decodes and re-encodes a packet fully before it is forwarded to the next destination. A relay can receive the signal from a neighboring relay only if they are in the same cluster. The solid line is an example of a route that connects nodes that exhibit the highest received SNR of each hop.

A. Conventional Multi-hop Relay Selection Approach

Given a source and a destination, relays are selected to provide the route that is the least error-prone in 2 selection phases [5]. In the first phase (phase 1), for any cluster *k* where

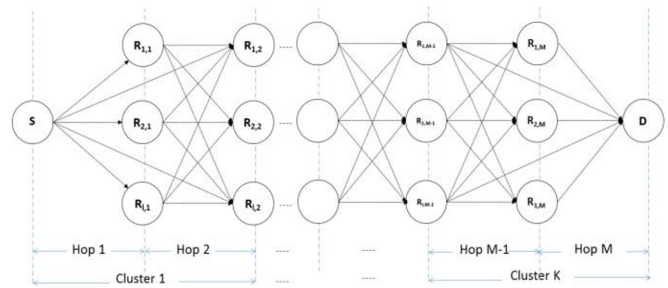


Fig. 4. An idealized linear network model with *M* hops, *L* relays, and *K* clusters, showing direct links in each cluster.

$k = 1, \ldots, K-1$, the relay (R_k^*) that exhibits the highest received SNR from S_0 is selected. R_k^* is found by solving $R_k^* = \arg\max_{R_{l,2k-1}} \left(\gamma_{S,R_{l,2k-1}}^{hop}\right)$, where $\gamma_{S,R_{l,2k-1}}$ (which is equal to $P_s\left|h_{S,R_{l,2k-1}}\right|^2/N_0$) represents the received SNR from *S* to $R_{l,2k-1}$ (where $l = 1, 2,\ldots, L$ and $2k$-1 are the indices of relays and the set of relays in the k^{th} cluster, respectively). The received signal at a selected relay R_k^* can be calculated from the following equation,

$$y_{S,R_k^*}^{hop} = \sqrt{P_S}h_{S,R_k^*}x + n_{R_k^*} \tag{1}$$

where P_s is the transmitted power from *S* to R_k^*, x is transmitted symbols, h_{S,R_k^*} is the channel impulse response of the SR_k^* link, and $n_{R_k^*}$ is the Additive White Gaussian Noise (AWGN) at R_k^*.

In phase 2, R_k^* decodes and re-encodes data then forwards them to a selected destination D_k^*. D_k^* is the node $D_{l,2k}$ that exhibits the highest received SNR from R_k^*. It is determined by solving $D_k^* = \arg\max_{D_{l,2k}}\left(\gamma_{R_k^*,D_{l,2k}}\right)$, where $\gamma_{R_k^*,D_{l,2k}}$ (which is equal to $P_R\left|h_{R_k^*,D_{l,2k}}\right|^2/N_0$) represents the received SNR from R_k^* to $D_{l,2k}$ of hop $2k^{\text{th}}$ ($l = 1, 2,\ldots, L$ and $2k$ are the indices of relays and the set of relays in the k^{th} cluster, respectively). R_k^* decodes and remodulates data $\tilde{x}$ before forwarding it to D_k^* in the k^{th} cluster. The received signal at a selected destination relay, $y_{R_k^*,D_k^*}^{hop}$, for multi-hop can be calculated from the following equation,

$$y = \sqrt{P_{R_k^*}} h_{R_k^*, D_k^*} \tilde{x} + n_{D_k^*} \quad (2)$$

where $P_{R_k^*}$ is the transmitted power from R_k^* to D_k^*, $\tilde{x}$ are remodulated data to be forwarded, $h_{R_k^*, D_k^*}$ is the channel impulse response between $R_k^* D_k^*$, and $n_{D_k^*}$ is the Additive White Gaussian Noise (AWGN) at D_k^* in the k^{th} cluster.

B. Modified Conventional Multi-hop Relay Selection Approach

For the last cluster, there is only one destination available which makes $D_k^* = D_0$. In this approach, the only major difference from the conventional multi-hop relay selection approach is that the last two hops in the *K*th cluster has to be handled jointly in order to achieve a higher diversity gain. For the hop 2*K*-1, instead of determining an R_k^* from the maximum $\gamma_{D_{M-2}^*, R_{l,M-1}}$ (which is equal to $\left| h_{D_{M-2}^*, R_{l,M-1}} \right|^2 / N_0$), we determined it from $\arg \max_{R_{l,M-1}} \left(\min \left(\gamma_{D_{M-2}^*, R_{l,M-1}}, \gamma_{R_{l,M-1}, D_0} \right) \right)$, where $\gamma_{D_{M-2}^*, R_{l,M-1}}$ (which is equal to $P_s \left| h_{D_{M-2}^*, R_{l,M-1}} \right|^2 / N_0$) is the received SNR between D_{M-2}^* (of hop $(M\text{-}2)^{th}$) and $R_{l,M-1}$, where l = 1, 2, …, L and M-1 are indices of relays and hops in the *Kth* cluster, respectively, and $\gamma_{R_{l,M-1}, D_0}$ (which is equal to $P_R \left| h_{R_{l,M-1}, D_0} \right|^2 / N_0$) is the received SNR between $R_{l,M-1}$ (of hop $(M\text{-}1)^{th}$) and D_0, where l = 1, 2, …, L and M-1 are indices of relays and hops in the *Kth* cluster. A summary of this routing strategy is shown in Table 1.

TABLE I
ROUTING STRATEGY FOR MODIFIED CONVENTIONAL MULTI-HOP RELAY SELECTION

Let l = 1, 2,…, L; m = 1, 2,…, M ; and k = 1, 2, …, K be the indices of relays, hops, and clusters in a communication network. Let S denotes the source node; R_k^* denotes the selected relay node in the k^{th} cluster; D_k^* denotes the selected destination node in the k^{th} cluster. A hop index m is always equals to 2k.

Initialization: $S = S_0$
Recursion:
For k = 1 to K-1
  $R_k^* = \arg \max_{R_{l,2k-1}} \left(\gamma_{S_0, R_{l,2k-1}} \right)$, l = 1, 2,…, L
  - Decode and remodulate at R_k^*
  - Send from R_k^* to D_k^*
  $D_k^* = \arg \max_{D_{l,2k}} \left(\gamma_{R_k^*, D_{l,2k}} \right)$, l = 1, 2,…, L
  - Decode and remodulate at D_k^*
  $S = D_k^*$
End
  $R_K^* = \arg \max_{R_{l,M-1}} \left(\min \left(\gamma_{D_{M-2}^*, R_{l,M-1}}, \gamma_{R_{l,M-1}, D_0} \right) \right)$, l = 1, 2,…, L
  $D_{K,}^* = D_0$
Output the optimal route $\{S_0, (R_k^*, D_k^*), D_0\}$, where k = 1, 2,…, K

The outage probability of this model is expressed in (3), which was derived for the Ad-hoc routing in [5],

$$P_{out,m}^{hop} = [I < th] = \begin{cases} \left(1 - \exp(-\frac{\gamma_{th}}{\delta_m^2 \gamma_0})\right)^L, & m = 1, 2, \dots, M-2 \\ 1 - \exp\left(\frac{(\delta_{M-1}^2 \delta_M^2)\gamma_{th}}{(\delta_{M-1}^2 \delta_M^2)\gamma_0}\right)^L, & m = M-1 \end{cases} \quad (3)$$

where δ_m^2 represents the attenuation with distance and shadowing at hop m^{th}, m = 1, 2,…, M; γ_0 is the SNR averaged over Rayleigh fading, ignoring the path loss and shadowing; γ_{th} represents the given SNR threshold; and L is the number of relay nodes in each hop l = 1, 2,…, L.

C. The proposed best destination relay selection (BDRS)

In this paper, we propose a BDRS strategy for improving the performance of a multi-hop relay communication system and reducing the system complexity. This strategy employs a cooperative protocol–directly transmitted signal from the source and signal from a selected relay in each cluster are combined at a destination node–together with an efficient node selection rule. In this section, the preliminary information of the strategy is presented first followed by the routing strategy

Figure 4 shows a picture of the idealized linear network model investigated in this study. It has one source (S), one destination (D), and M – 1 hops where each hop has L nodes that can function as a relay or a destination node in each cluster. A cluster can be viewed as a combination of one source, L relays, and L destination nodes in every two consecutive hops. The relationship between the index of cluster (k) and index of hop (m) is m = 2k. A direct link is a link between *S-D*, and an indirect link is a link via a cooperative relay *S-R-D*. The following are the characteristics of our model: the variance of additive white Gaussian noise (AWGN) is $N_0/2$ per complex dimension; the channel impulse response in this system is Rayleigh slow fading; the channel quality is checked periodically to enable adaptive feature; all channel links are statistically independent to each other; and a Time Division Multiple Access (TDMA) technique was applied in signal transmission. Specifically, TDMA was applied in each phase of the two transmission phases of the cooperative protocol as follows: in phase 1, S broadcasts a signal to $R_{l,m}$ and $D_{l,m}$ within a cluster; and in phase 2, $R_{l,m}$ detects the signal from S and remodulates it before transmitting the remodulated signal to $D_{l,m}$. $D_{l,m}$ of a previous cluster is the source ($S_{l,m}$) of the next cluster. The destination node ($D_{l,m}$) combines the signals from

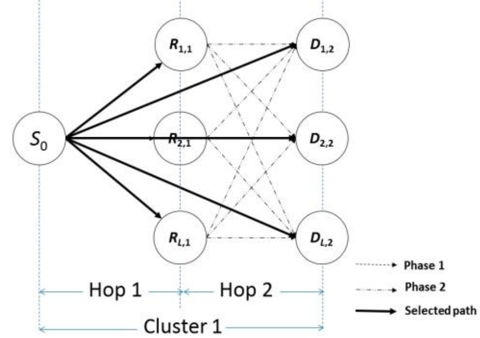


Fig. 5. The idealized linear network model with M hops and L relays in the 1st cluster for analyzing BDRS routing strategy.

S and $R_{l,m}$ using a maximum ratio combining (MRC) technique [11].

As for the BDRS routing strategy, we describe it by showing an analysis of only the first cluster, depicted in Figure 4. Other clusters can be analyzed in exactly the same way, up to the *K*-1th cluster. The last cluster (the *Kth* cluster) has only one final destination node; therefore, our protocol does not apply, and instead, selection of the best relay is performed according to the method in [7]. We considered only the case of $L = 3$ and $M = 2$ for our analysis, but it can be generalized to the cases of $l = 1, 2,\ldots, L$ and $M = 2$.

Figure 5 shows a BDRS implementation in the first cluster of our modified conventional multi-hop communication model (illustrated in Figure 1). The model's cooperative protocol has an advantage of evenly broadcasting a signal from a source to all nodes in a cluster, including the selected destination node of the cluster. The proposed BDRS strategy, which is implemented in 2 phases, can be described as follows. The first node that transmits a signal is defined as $S = S_0$, and the destination node that receives a signal is $D = D_k$. Any number of *k* clusters, where $k = 1,\ldots, K-1$, can be between the 2 nodes. In phase 1, a destination relay that exhibits the maximum received SNR is selected (D_k^*). D_k^* is found by calculating $\arg\max_{D_{l,2k}}\left(\gamma_{S,D_{l,2k}}\right)$, where $l = 1, 2,\ldots, L$ and $k = 1, 2,\ldots, K$-1, and $\gamma_{S,D_{l,2k}}$ (calculated from $P_S\left|h_{S,D_{l,2k}}\right|^2/N_0$) represents the SNR from *S* to $D_{l,2k}$, where $l = 1, 2,\ldots, L$. The expression for the received signal is

$$y_{S,D_k^*}^{coop} = \sqrt{P_S}h_{S,D_k^*}x + n_{SD_k^*}, \tag{4}$$

where P_S is the transmitted power from *S* to *D*, x represents modulated transmitted symbols, h_{S,D_k^*} is the channel impulse response from *S* to *D*, and $n_{SD_k^*}$ is AWGN from *S* to *D*.

In phase 2, a relay R_k^* is selected that exhibits the minimum outage probability (P_{out}), where $R_k^* = \arg\min_{R_{l,2k-1}}(P_{out})$ and P_{out} is as expressed in (19). R_k^* receives a broadcast signal from the source, detects $\tilde{x}$ by using a Maximum-Likelihood (ML) technique, and decodes and re-encodes the $\tilde{x}$ before transmitting it to the next destination node D_k^*. The optimal route is then the best one in the set of a-node-to-another-node routes $\{\mathbf{R}\} = \{S_0, (R_k^*, D_k^*), (R_K^*, D_0)\}$, and $k = 1, 2,\ldots, K$. The received signal from R_k^* to D_k^* can be expressed as follows,

$$y_{R_k^*,D_k^*}^{coop} = \sqrt{P_{R_k^*}}h_{R_k^*,D_k^*}\tilde{x} + n_{R_k^*D_k^*}, \tag{5}$$

where $P_{R_k^*}$ is the transmitted power from R_k^* to D_k^*, $\tilde{x}$ represents the decoded transmitted symbols, $h_{R_k^*,D_k^*}$ represents the channel impulse response from the selected R_k^* to D_k^* in cluster k^{th}, $n_{R_k^*D_k^*}$ represents the Additive White Gaussian Noise (AWGN) from the selected R_k^* to D_k^*.

The destination relay (D_k^*) combines the received signals from *S* and R_k^* using a cooperative maximum ratio combining (C-MRC) technique presented in [12]. Note that, at high $\gamma_{SR_k^*}$, the node that detects the signal places full confidence on the arriving signals from the relay. At low $\gamma_{SR_k^*}$, its confidence is weighted according to the ratio of both hops, which are the SR_k^* and $R_k^*D_k^*$ routes. The received symbols were detected by using the maximum likelihood (ML) technique. Then, the destination relay (D_k^*) functions as the source ($S_{l,2k-2}$) for the next consecutive cluster. The received signal is detected and re-encoded before the re-encoded signal is transmitted to a relay in the next cluster. The received signal can be calculated from the following expression,

$$y_{\text{C-MRC}}^{coop} = \left(\frac{\sqrt{P_S}h_{SD_k^*}^*y_{SD_k^*}}{n_{D_k^*}}\right) + \left(\frac{\min\left(\gamma_{SR_k^*},\gamma_{R_k^*D_k^*}\right)}{\gamma_{R_k^*D_k^*}}\right)\left(\frac{\sqrt{P_R}h_{R_k^*D_k^*}^*y_{R_k^*D_k^*}}{n_{D_k^*}}\right) . \tag{6}$$

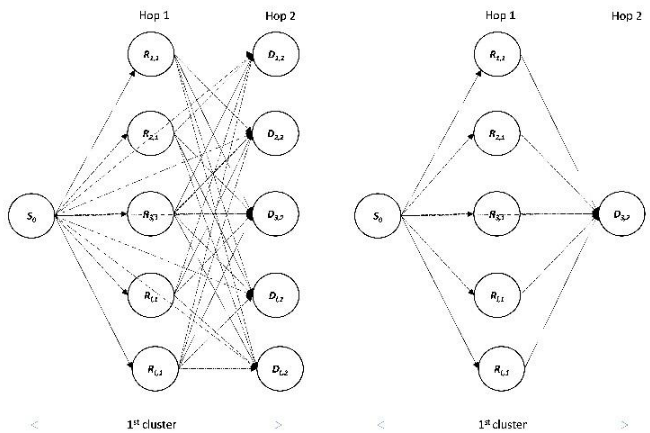
For the last cluster, a cooperative relay R_K^* is selected such that it exhibits the minimum outage probability ($R_K^* = \arg\min_{R_{l,2K-1}}(P_{out})$). Our proposed protocol is summarized in Table 2 as follows.

TABLE II
ROUTING STRATEGY FOR THE PROPOSED BDRS

Let $l = 1, 2,\ldots, L$ be the index of relay nodes; $m = 1, 2,\ldots, M$ be the index of communication hops; and $k = 1, 2,\ldots, K$ be the index of clusters in a communication network. Let *S* denotes the source node; R_k^* denotes the selected relay node in the k^{th} cluster; and D_k^* denote the selected destination node in the k^{th} cluster; and note that a hop index $m = 2k$.

Initialization: $S = S_0$
Recursion:
For $k = 1$ to K-1
$D_k^* = \arg\max_{D_{l,2k}}\left(\gamma_{S,D_{l,2k}}\right)$, $l = 1, 2,..., L$
$R_k^* = \arg\min_{R_{l,2k-1}}(P_{out})$ (P_{out} expression is in (19))
- Decode at R_k^* and remodulate
- Send from R_k^* to D_k^*
- Combine signals by using C-MRC represented by (6)
- Decode at R_k^* and remodulate at D_k^*
$S = D_k^*$
End
$D_K^* = D_0$
$R_K^* = \arg\min_{R_{l,M-1}}(P_{out})$ (P_{out} is expressed in (19))
Output the optimal route $\{S_0, (R_k^*, D_k^*), (R_{M-1}^*, D_0)\}$, $k = 1, 2,\ldots, K$

In order to implement a cooperative protocol in a multi-hop relay system, we have to find two optimum nodes, i.e., one is the cooperative relay node and the other one is the destination node. We found that the proposed BDRS can reduce the computational complexity by searching only *L* times compared to the heuristic strategy that searches all nodes, as illustrated in Figure 6 (a) and (b). In the latter strategy, the source has to search for the best relay node and the best destination node from all nodes in order to minimize the outage probability. In contrast, the proposed BDRS reduces the system complexity from an exponential function of L^m to a linear function of L, where L is the number of relays in each hop and m is the number of hops. In Figure 6, $m = 2$; the cluster consists of two hops. The proposed BDRS can reduce the complexity of clusters $k = 1$ to $k = K-1$. The complexity of the last cluster ($k = K$) is, however, the same because there is only one final destination.



(a) Heuristic Searching Strategy. (b) The proposed BDRS searching strategy.

Fig. 6. Comparison of complexity for two different searching strategies.

III. Performance Analysis

In this section, we derive a closed-form expression of the outage probability for our BDRS protocol. The number of hops (M) was set to be 2, the number of cooperative relays (L) to be 1, and the number of destination relays (L) to be 3. We call this configuration 1R3D. We picked 1R3D as the best configuration to show the derivation of our protocol because a configuration of 3 Ds shows sufficiently the complexity of the derivation in a manageable length. Furthermore, any configuration with a higher number of Ds can be derived by using the same principle. We only consider the outage probability of a system with one relay for the reason that the best relay of a system with more relays can be selected in the same way by applying this expression to each relay, one-by-one, and choosing the relay with the minimum outage probability among all of the relays.

Our derivation starts by, first, finding the mutual information between S and $R_{l,2k-1}$, as shown below,

$$I_{SR_{l,2k-1}} = \frac{1}{2} log_2\left(1 + \gamma_{SR_{l,2k-1}}\right),\ l = 1,2,\ldots,L \text{ and } k = 1,2,\ldots,K \qquad (7)$$

where $\gamma_{SR_{l,2k-1}} = P_S|h_{SR_{l,2k-1}}|^2/N_0$ is the instantaneous SNR between S and $R_{l,2k-1}$ and $h_{SR_{l,2k-1}}$ is the channel impulse response between S and $R_{l,2k-1}$. If $I_{SR_{l,2k-1}}$ is higher than a given threshold (th) specified by the system designer according to the type of application, the relay $R_{l,2k-1}$ decodes and retransmits the signal to a selected destination relay (D_k^*). The reason why we have a factor of 1/2 in (7) is because we use two time slots (or orthogonal channels) for data transmission. The mutual information between S and D for the proposed BDRS protocol can be written as

$$I_{DF} = \frac{1}{2} log_2\left(1 + \max_{l=1,\ldots,L}(\gamma_{SD_{l,2k}}) + \gamma_{R_{l,2k-1}D_k^*}\right),$$
$$l = 1,2,\ldots,L \text{ and } k = 1,2,\ldots,K \qquad (8)$$

where $\gamma_{SD_{l,2k}} = P_S|h_{SD_{l,2k}}|^2/N_0$ is the instantaneous SNR between S and $D_{l,2k}$ at hop $m = 2k$ and $\gamma_{R_{l,2k-1}D_k^*} = P_R|h_{R_{l,2k-1}D_k^*}|^2/N_0$ is the instantaneous SNR between $R_{l,2k-1}$ and D_k^* at the cluster k^{th}. In fact, the mutual information in (8) can be determined by the BDRS selection principle that selects the destination node with the maximum received SNR first then uses the node to retransmit the signal. Based on the principle of C-MRC signal combining [12], the total received SNR (SNR_{total}) is the summation of the received SNR from both the direct and indirect links, i.e., $SNR_{total} = \max_{l=1,2,3}(\gamma_{SD_{l,2}}) + \gamma_{R_{l,2k-1}D_k^*}$. From a general principle together with the expression for mutual information in (8), a general form of the outage probability can be expressed as follows,

$$P_{out} = \Pr(I_{DF} \le th)$$
$$= \Pr\left(\max_{l=1,\ldots,L}(\gamma_{SD_{l,2k}}) + \gamma_{R_{l,2k-1}D_k^*} \le 2^{2th} - 1\right) \qquad (9)$$

where $l = 1,2,\ldots,L$ and $k = 1,2,\ldots,K$.

For the purpose of making the derivation clear and easy to understand, only the first cluster of our model is considered. We present the derivation of the outage probability (P_{out}) in steps as follows: 1) determine the distribution of the total received SNR (SNR_{total}) by using a moment generating function (MGF). Since MGF of SNR_{total} is equal to the product of MGF of $\max_{l=1,\ldots,L}(\gamma_{SD_{l,2k}})$ and MGF of $\gamma_{R_{2k-1}D_{l,2k}^*}$, we have to determine each MGF separately and derive the probability density function (PDF) by applying an inverse Laplace transform to the MGF of SNR_{total}; 2) determine P_{out} by calculating a cumulative distribution function (CDF) with respect to the outage threshold (th) which can be found directly by integrating its PDF from the previous step.

In order to simplify the analysis in step 1, we introduce a new random variable $\mathcal{Z}$ which is a sum of two random variables, $Z = \chi + \gamma_{R_{1,1}D_2^*}$ where $\chi = \max_{l\epsilon\{1,2,3\}}(\gamma_{SD_{l,2}})$. Now, the outage probability can be written as $P_{out} = \Pr(\mathcal{Z} \le 2^{2th} - 1)$. Therefore, the CDF of the received signal can be obtained directly from the PDF of $\mathcal{Z}$ evaluated at $2^{2th} - 1$ since the two random variables χ and $\gamma_{R_{1,1}D_2^*}$ are statistically independent, and the PDF of $\mathcal{Z}$ is just the convolution of the PDFs of χ and $\gamma_{R_{1,1}D_2^*}$ (its calculation method reported in [13]). The PDF of χ can be found from the CDF of χ as follows,

$$F_\chi(x) = \Pr\left(\max_{l\epsilon 3}(\gamma_{SD_{l,2}}) \le x\right)$$
$$= \prod_{l=1}^{3} \Pr(\gamma_{SD_{l,2}} \le x) = \prod_{l=1}^{3} F_{\gamma_{SD_{l,2}}}(x) \qquad (10)$$

$$f_{\chi}(x)=\sum_{l=1}^{3}\exp\left(-\frac{x}{\gamma_{SD_{l,2}}}\right)-\left(\left(\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}}\right)\frac{\exp\left(-\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)x}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)-\left(\left(\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}}\right)\frac{\exp\left(-\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)x}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)$$
$$-\left(\left(\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}\right)\frac{\exp\left(-\frac{\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)x}{\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)+\left(\left(\gamma_{SD_{1,2}}\left(\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}\right)+\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}\right)\frac{\exp\left(-\frac{\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}+\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)x}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right) \quad (11)$$

$$M(f_{\chi}(x))=\sum_{l=1}^{3}\exp\left(-\frac{\frac{1}{\gamma_{SD_{l,2}}}}{\frac{1}{\gamma_{SD_{l,2}}}-s}\right)-\left(\frac{\left(\frac{1}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)(\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}})}{\left(\left(\frac{1}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)(\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}})\right)-s}\right)$$
$$-\left(\frac{\left(\frac{1}{\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)(\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}})}{\left(\left(\frac{1}{\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)(\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}})\right)-s}\right)-\left(\frac{\left(\frac{1}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)(\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}})}{\left(\left(\frac{1}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)(\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}})\right)-s}\right)$$
$$-\left(\frac{\left(\frac{\left(\gamma_{SD_{1,2}}\left(\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}\right)+\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}\right)}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)}{\left(\frac{\left(\gamma_{SD_{1,2}}\left(\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}\right)+\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}\right)}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)-s}\right). \quad (12)$$

$$f_{\gamma_{R_{1,1}D_2^*}}(x)=f_{\gamma_{R_{1,1}D_2^*}|R_{1,1}\text{ is off}}(x)\Pr(R\text{ is off})+f_{\gamma_{R_{1,1}D_2^*}|R_{1,1}\text{ is on}}(x)\Pr(R\text{ is on}) \quad (13)$$

$$A=\Pr(I\le th)=\Pr\left(\gamma_{SR_{1,1}}\le 2^{2th}-1\right)=1-\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SR_{1,1}}}\right) \quad (14)$$

$$f_{\gamma_{R_{1,1}D_2^*}|R_{1,1}\text{ is on}}(x)=\frac{1}{\bar{\gamma}_{R_{1,1}D_2^*}}\exp\left(-\frac{x}{\bar{\gamma}_{R_{1,1}D_2^*}}\right),\ x\ge 0 \quad (15)$$

$$f_{\gamma_{R_{1,1}D_2^*}}(x)=A\delta(x)+(1-A)\frac{1}{\bar{\gamma}_{R_{1,1}D_2^*}}\exp\left(-\frac{x}{\bar{\gamma}_{R_{1,1}D_2^*}}\right),\ x\ \ge 0. \quad (16)$$

$$M(f_{\gamma_{R_{1,1}D_2^*}}(x))=A\delta(x)+(1-A)\left(\frac{\bar{\gamma}_{R_{1,1}D_2^*}}{\bar{\gamma}_{R_{1,1}D_2^*}-S}\right) \quad (17)$$

$$
\begin{aligned}
F_Z(x) &= A\sum_{l=1}^{3}\left(1-\exp\left(-\frac{x}{\gamma_{SD_{l,2}}}\right)\right)+\sum_{l=1}^{3}\left\{\frac{\exp\left(-\frac{x}{\gamma_{SR_{1,1}}}\right)}{\frac{1}{\gamma_{SD_{l,2}}}-\frac{1}{\gamma_{R_{1,1}D_{l,2}}}}\left[\frac{1}{\gamma_{SD_{l,2}}}\left(1-\exp\left(-\frac{x}{\gamma_{R_{1,1}D_{l,2}}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_{l,2}}}\left(1-\exp\left(-\frac{x}{\gamma_{SD_{l,2}}}\right)\right)\right]\right\}\\
&-\mathrm{A}\left(1-\exp\left(-x\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)\right)-\frac{\exp\left(-\frac{x}{\gamma_{SR_{1,1}}}\right)}{\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}}\left[\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)\left(1-\exp\left(-\frac{x}{\gamma_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}\left(1-\exp\left(-x\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)\right)\right]\\
&-\mathrm{A}\left(1-\exp\left(-x\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)\right)-\frac{\exp\left(-\frac{x}{\gamma_{SR_{1,1}}}\right)}{\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}}\left[\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)\left(1-\exp\left(-\frac{x}{\gamma_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}\left(1-\exp\left(-x\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)\right)\right]\\
&+\mathrm{A}\left(1-\exp\left(-x\frac{\gamma_{SD_{1,2}}\left(\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}\right)+\left(\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}\right)}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)\right)-\frac{\exp\left(-\frac{x}{\gamma_{SR_{1,1}}}\right)}{\left(\frac{\gamma_{SD_{1,2}}\left(\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}\right)+\left(\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}\right)}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}}\\
&\times\left[\left(\frac{\gamma_{SD_{1,2}}\left(\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}\right)+\left(\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}\right)}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)\left(1-\exp\left(-\frac{x}{\gamma_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}\left(1-\exp\left(-x\frac{\gamma_{SD_{1,2}}\left(\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}\right)+\left(\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}\right)}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)\right)\right] \quad (18)
\end{aligned}
$$

$$
\begin{aligned}
P_{out}^{coop} &= \left[1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)\right]\sum_{l=1}^{3}\left[1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SD_{l,2}}}\right)\right]\\
&+\sum_{l=1}^{3}\left\{\frac{\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)}{\left(\frac{1}{\gamma_{R_{1,1}D_{l,2}}}-\frac{1}{\gamma_{R_{1,1}D_2^*}}\right)}\left[\frac{1}{\gamma_{SD_{l,2}}}\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SD_{l,2}}}\right)\right)\right]\right\}\\
&-\left[\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)\right)\left(1-\exp\left(-\frac{(2^{2th}-1)(\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}})}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)\right)\right]\\
&-\left[\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)\right)\left(1-\exp\left(-\frac{(2^{2th}-1)(\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}})}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)\right)\right]\\
&-\left[\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)\right)\left(1-\exp\left(-\frac{(2^{2th}-1)(\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}})}{\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)\right)\right]\\
&-\frac{\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)}{\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}}\left[\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}\left(1-\exp\left(-(2^{2th}-1)\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)\right)\right)\right]
\end{aligned}
$$

$$-\frac{\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)}{\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}}\left[\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}\left(1-\exp\left(-(2^{2th}-1)\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)\right)\right)\right]$$

$$-\frac{\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)}{\left(\frac{\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}}\left[\left(\frac{\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}\left(1-\exp\left(-(2^{2th}-1)\left(\frac{\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)\right)\right)\right]$$

$$+\frac{\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)}{\sum_{l=1}^{3}\frac{1}{\gamma_{SD_{l,2}}}-\frac{1}{\gamma_{R_{1,1}D_2^*}}}\left[\sum_{l=1}^{3}\frac{1}{\gamma_{SD_{l,2}}}\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}\left(1-\exp\left(-(2^{2th}-1)\sum_{l=1}^{3}\frac{1}{\gamma_{SD_{l,2}}}\right)\right)\right]. \quad (19)$$

where $F_{\gamma_{SD_{l,2}}}(x)$ is the CDF of $\gamma_{SD_{l,2}}$ and $F_{\gamma_{SD_{l,2}}}(x) = 1 - \exp(\frac{-x}{\bar{\gamma}_{SD_{l,2}}})$. By using the expression for the CDF of $\gamma_{SD_{l,2}}$ the expression for the PDF of χ can be found by taking the derivative of (10) with respect to x, and after some manipulations, $f_{\chi}(x)$ can be written as (11). To determine the MGF of $\gamma_{R_{2k-1}D_{l,2k}^*}$, we obtain it from the PDF of $\gamma_{R_{1,1}D_2^*}$, expressed in (12).

The operation of the relay can be explained as follows. When I is equal or less than th, the received SNR at the destination sent by $R_{1,1}$ is 0 since there is no signal retransmission from $R_{1,1}$. Therefore, the conditional PDF $f_{\gamma_{R_{1,1}D_2^*}|R \text{ is off}}(x)$ can be expressed as $f_{\gamma_{R_{1,1}D_2^*}|R \text{ is off}}(x) = \delta(x)$ (i.e., when the mutual information of SR is less than th, $I \leq I_{th}$). We define an outage probability for when $R_{1,1}$ is off as A, expressed in (14) where $\bar{\gamma}_{SR_{1,1}} = \mathbf{E}\left(\frac{P_S|h_{SR_{1,1}}|^2}{N_0}\right)$ stands for the average SNR between S and $R_{1,1}$ and $\mathbf{E}(\cdot)$ is a statistical expectation operator. When $I > I_{th}$, the outage probability that $R_{1,1}$ is on is $(1-A)$ and the conditional PDF $f_{\gamma_{R_{1,1}D_2^*}|R_{1,1} \text{ is on}}(x)$ can be written as (15)

where $\bar{\gamma}_{R_{1,1}D_2^*} = \mathbf{E}\left(\frac{P_R|h_{R_{1,1}D_2^*}|^2}{N_0}\right)$ stands for the average SNR between $R_{1,1}$ and D_2^*. Therefore, the PDF of $\gamma_{R_{1,1}D_2^*}$ can be written as shown in (16). The MGF of $f_{\gamma_{R_{1,1}D_2^*}}(x)$ can be obtained by transforming (16) from time domain to frequency domain, expressed in (17). Multiplying (12) with (17) and then inverse Laplace transforming the multiplication product to time domain, we obtain expression (18) for the CDF of Z.

Lastly, in order to find P_{out} in step 2, we integrate directly the CDF expression in (18) with respect to the given threshold (th). Hence, in general, P_{out} can be expressed as $P_{out} = \Pr(Z \leq 2^{2th}-1) = F_Z(2^{2th}-1)$. For the 1$R3D$ configuration, P_{out} of a cluster becomes (19). The derivation of (19) is shown in the Appendix.

For comparison, we also derive the outage probability for 1R1D and 1R2D systems in the same manner. In principle, our derivation procedure can be applied to a system of any numbers of relays and destinations.

The outage probability for the 1R1D configuration is as follows,

$$P_{out}^{coop} = \left[1-\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SR_{1,1}}}\right)\right]\left[1-\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SD_{1,2}}}\right)\right]+\frac{\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SR_{1,1}}}\right)}{\left(\frac{1}{\bar{\gamma}_{SD_{1,2}}}-\frac{1}{\bar{\gamma}_{RD_{1,2}}}\right)}\left[\frac{1}{\bar{\gamma}_{SD_{1,2}}}\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{R_{1,1}D_{1,2}}}\right)-\frac{1}{\bar{\gamma}_{R_{1,1}D_{1,2}}}\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SD_{1,2}}}\right)\right] \quad (20)$$

The outage probabilities for the 1R2D is as follows,

$$P_{out}^{coop}=\left[1-\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SR_{1,1}}}\right)\right]\sum_{l=1}^{2}\left[1-\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SD_{l,2}}}\right)\right]+\sum_{l=1}^{2}\frac{\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SR_{1,1}}}\right)}{\left(\frac{1}{\bar{\gamma}_{SD_{l,2}}}-\frac{1}{\bar{\gamma}_{R_{1,1}D_2^*}}\right)}\left[\frac{1}{\bar{\gamma}_{SD_{l,2}}}\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{R_{1,1}D_2^*}}\right)-\frac{1}{\bar{\gamma}_{R_{1,1}D_2^*}}\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SD_{l,2}}}\right)\right]$$
$$-\left[1-\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SR_{1,1}}}\right)\right]\left[1-\exp\left(-\left(2^{2th}-1\right)\sum_{l=1}^{2}\left(\frac{1}{\bar{\gamma}_{SD_{l,2}}}\right)\right)\right]$$
$$-\frac{\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SR_{1,1}}}\right)}{\sum_{l=1}^{2}\left(\frac{1}{\bar{\gamma}_{SD_{l,2}}}\right)-\frac{1}{\bar{\gamma}_{R_{1,1}D_2^*}}}\left[\sum_{l=1}^{2}\left(\frac{1}{\bar{\gamma}_{SD_{l,2}}}\right)\left(1-\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\bar{\gamma}_{R_{1,1}D_2^*}}\exp\left(-\frac{\left(2^{2th}-1\right)\sum_{l=1}^{2}\left(\frac{1}{\bar{\gamma}_{SD_{l,2}}}\right)}{\bar{\gamma}_{SD_{2,2}}}\right)\right] \quad (21)$$

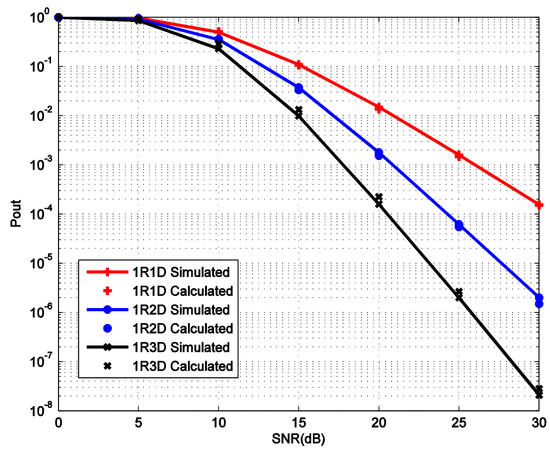


Fig. 7. Simulated and calculated performances of BDRS (first cluster, fixed source, 1 relay node, and 1-3 destination nodes).

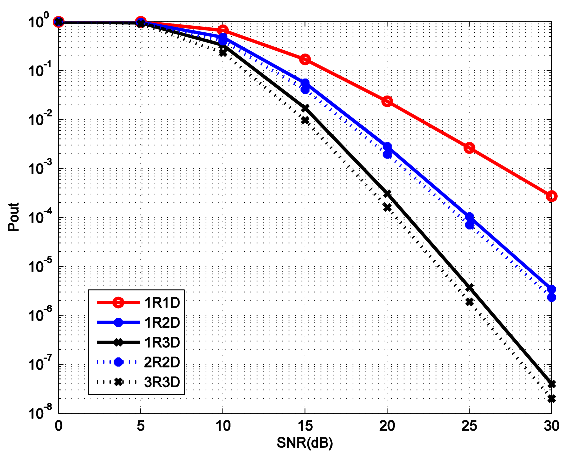


Fig. 8. Simulated performance of BDRS with various numbers of relay and destination nodes (first cluster, fixed source, 1-3 relays, and 1-3 destinations).

IV. Simulation Results

Based on computer simulation with MATLAB software, the performance of the BDRS system was determined and compared with that from the closed-form expression (19). Simulation settings were as follows: binary phase shift keying (BPSK) modulation was used with a total transmitted power of 1 Watt; noise variance was N_0; and bandwidth efficiency was 1 bit/s/Hz. In addition, Jake's model [14] was employed for simulating Rayleigh fading channels with normalized Doppler shift of 5,000 Hz, and all channel link variances in the system were assumed to be dependent on the distance between nodes in an idealized linear system.

Figure 7 shows the simulated and calculated performances of the first cluster of 3 different configurations of a system: 1*R*2*D*, 1*R*2*D*, and 1*R*3*D*. It can be seen that the performances were very close. Note that the BDRS protocol reduced the system complexity from L^2 to L, compared to that of searching for the best case of all cases in the same cluster in a non-augmented cooperative protocol.

Figure 8 depicts the performances 4 configurations of a system: 1*R*1*D*, 1*R*2*D*, 1*R*3*D*, 2*R*2*D*, and 3*R*3*D*. The performance curves show that when the number of destination nodes was fixed, more relays resulted in more coding gain. Moreover, the curves in this figure and in Figure7 indicate that the diversity gain was dependent on the number of destination nodes, and the coding gain was dependent on the number of cooperative relay nodes.

Figure 9 shows the simulated performances of the proposed BDRS strategy versus the modified conventional multi-hop strategy for 3 clusters, as an extension for the cases of only 1 cluster above. The result shows that the proposed strategy outperformed the modified conventional multi-hop communication strategy dramatically–the SNR differences for 1*R*1*D*, 2*R*2*D*, 3*R*3*D*, 4*R*4*D*, and 5*R*5*D* configurations were 5, 9, 12, 13 and 13 dB, respectively, at P_{out} of 10^{-2}. In addition, at a high SNR regime, as the number of destination relays increased, the proposed protocol achieved more diversity gain.

Figure 10 shows simulated performances for 3 clusters as the source was fixed or moving. When the source moved, channel variances were changed from the distance variation. BDRS will adaptively search for the new best destination, and then the new best relay with minimum outage probability. The software was set to simulate the source moving randomly up and down vertically in every 10,000 bits transmission. It can be seen that

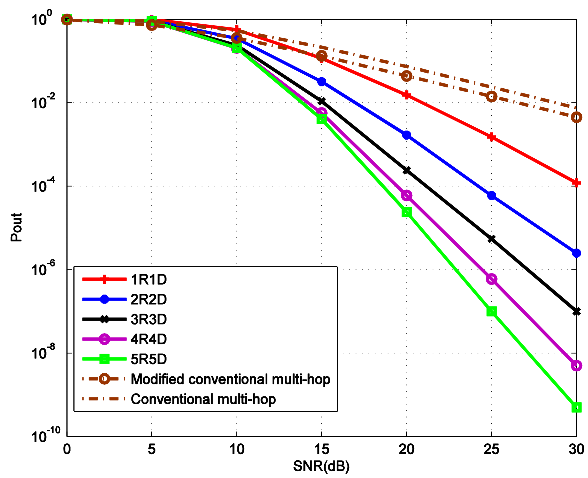


Fig. 9 Simulated performances for three clusters of the proposed BDRS, conventional multi-hop, and modified conventional multi-hop.

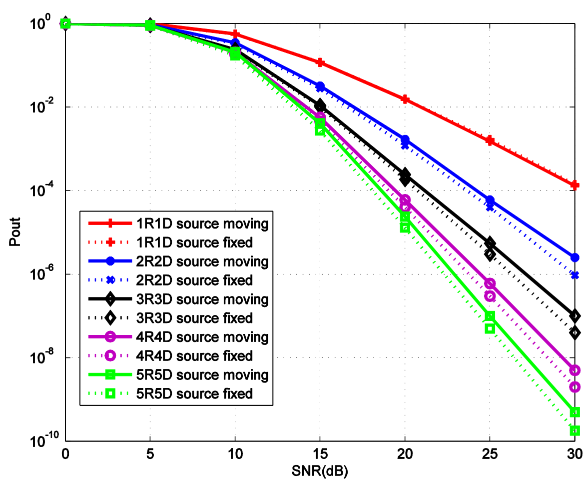


Fig.10 Simulated performances for 3 clusters with the source fixed or moving.

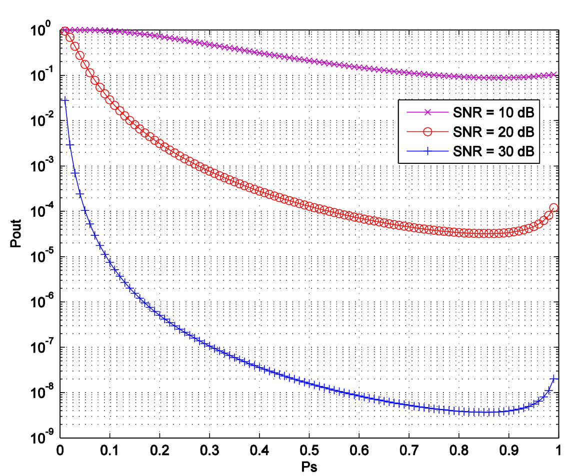


Fig. 11. P_{out} of BDRS (1*R*3*D*) with fixed SNR at various source transmitting powers at SNR =10, 20, and 30 dB.

moving source deteriorate the performances marginally, but would not be as much as that of a non-adaptive protocol.

V. Performance Improvement

This section discusses the general concept of power allocation, implementation issue, and the results. In principle, C-MRC alone cannot guarantee maximum total SNR at the destination, but by varying power allocation according to channel quality, system performance should be improved. The objective of power allocation is to selectively allocate certain transmitted power to source (P_S) and relay (P_R,) such that the total transmitted power (P_T) is fixed, in order to minimize P_{out}. We can write the power allocation condition as follows,

$$P_T = \lambda P_S + (1-\lambda)P_R \quad \text{at } 0 < \lambda < 1, \tag{22}$$

where λ is the power allocation factor between P_S and P_R.

In this study, the optimum power allocation was determined by replacing P_R with $(1-\lambda)P_S$ and P_S with λP_S in the expression for outage probability (19) and then heuristically varying λ from 0 to 1 until the minimum outage probability was found. Graphs of P_{out} as a function of λ at SNR = 10dB, 20dB, and 30dB were plotted in Figure 11. To find the minimum outage probability $\left(\min(P_{out})\right)$ from the curves, normally we take a derivative of (19) with respect to P_S and set it equal to zero then algebraically solve the equation. However, this expression is very difficult to solve in closed-form, so we determined the minimum outage probability by finding the zero-crossing as follows,

$$\frac{dP_{out}^{coop}(\lambda)}{d\lambda} = 0 \tag{23}$$

In detail, Figure 12 shows the optimum power allocation in the first cluster of 1*R*3*D* configuration. The crossing point at x-axis is the source power that yields the minimum outage probability. This figure shows how much power of a total of 1 Watt should be allocated between the source and the relay when the channel quality of each link changes at a fixed SNR = 20 dB. The results indicate that more power—0.83, 0.93, and 0.81 Watt—should be allocated to the source when the qualities of the *SD* link, *SR* link, and *RD* link, respectively, were set to be poor one at a time. The rest of the power (P_R) should be allocated to the cooperative relay.

In Figure 13, the effects of channel variances (δ^2) on power allocation are shown in plots of P_{out} as a function of λ at SNR = 10 dB (Figure 11a), SNR = 20 dB (Figure 11b), and SNR = 30 dB (Figure 11c) where ($\delta_{SD}^2 = 0.1, \delta_{SR}^2 = 1, \delta_{RD}^2 = 1$), ($\delta_{SD}^2 = 1, \delta_{SR}^2 = 0.1, \delta_{RD}^2 = 1$), and ($\delta_{SD}^2 = 1, \delta_{SR}^2 = 1, \delta_{RD}^2 = 0.1$) for each SNR case. The results show that the optimum power allocation was always with λ more than 0.5 in all cases.

VI. Implementation Issues

In this section, we discuss the following: cases when central control is available and when control is unavailable, error detection, channel estimation when source is moving, collision problem, and an issue regarding odd hops.

Following the BDRS strategy, the best destination for each cluster is selected first based on received SNR, or equivalently, measured channel gain. Selection can be implemented in either a centralized or distributed way. If a central controller is available (such as the cases of base station in a cellular network or an access point in a mesh network), it can collect all channel state information (CSI) and then assign a transmission. In the case where a central controller is not available, BDRS strategy can also be implemented in a distributed way by using a distributed relay selection algorithm proposed in [15] where each relay sets a timer based on its measured channel gain. The larger the channel gain is, the shorter the receiving time is. In this way, the timer of the destination with the best channel, i.e,, the best destination selected, expires first. That destination then sends a flag signal. All other destinations, while waiting for their timer to count down to zero, are in listening mode. As soon as they hear the flag signal, they back off. This method requires that every destination can hear all the others. For error detection, cyclic redundancy check (CRC), commonly used in wireless communication systems, is applied to the selected node. For estimation of channel impulse response when the source is moving, a short-term statistical technique reported in [16] that levels out short-term changes can be employed. To deal with possible hidden-node collisions, each relay can randomly stop transmitting then wait and see if other relays are re-transmitting. Finally, it may seem that the proposed BDRS is limited to systems consisting of even hops, however, that is not the case. When a system consists of odd hops, the BDRS strategy works by selecting the best relay at hop M-1, from the neighboring nodes in the same hop, which will then cooperate with the source to retransmit the signal to the final destination.

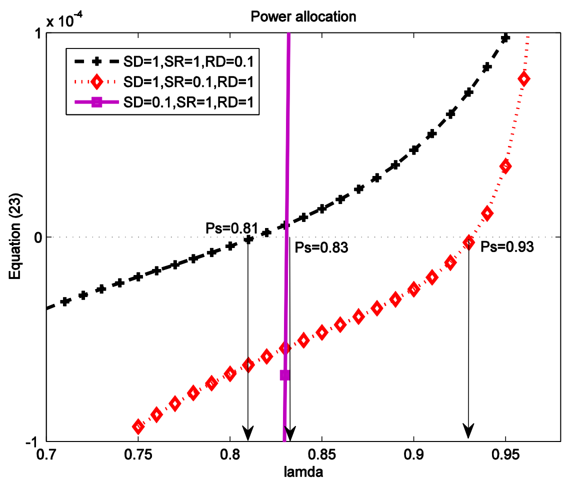


Fig. 12. Optimum power for the first cluster, found by searching for zero crossing of (23)

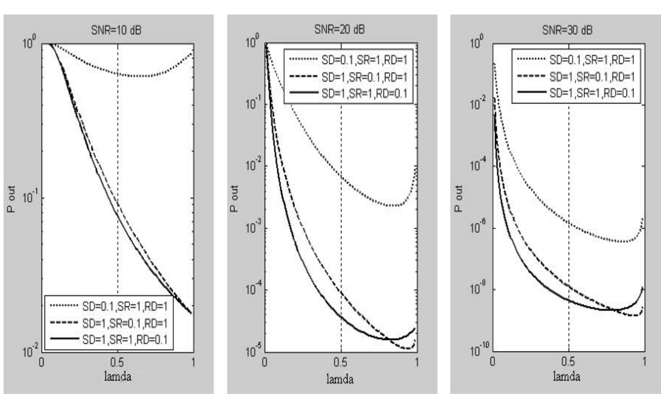


Fig. 13. P_{out} of BDRS (1*R*3*D*) at various transmitting powers, SNRs, and channel variances.

VII. Conclusion

In this paper, we propose an adaptive cooperative protocol for multi-hop wireless network with a ‘best destination relay selection’ (BDRS) routing protocol. The proposed routing protocol was designed to achieve an optimal route while reducing system complexity. To assess the performance of the proposed protocol, its operations in a system with different numbers of hops and clusters were simulated and their results were compared to those of the conventional multi-hop and modified conventional multi-hop protocols. It was found that our proposed protocol outperformed those protocols by several folds–it achieved a 15 dB and 14 dB received SNR improvement gains, respectively, at an outage probability of less than 10^{-2}. Moreover, we found that the simulated results agreed closely with the calculated results from the exact, closed-form mathematical expression of the outage probability of our proposed protocol. Lastly, we used an optimum power allocation scheme to further improve the system performance and found that its operation supported our reasoning that the direct source to destination link is the most important link.

Appendix

A. Derivation for the 1R1D configuration

Let u be the CDF of the received SNR of a direct link and v is the CDF of the received SNR of an indirect link as follows,

$$u = 1 - e^{-\frac{x}{\bar{\gamma}_{SD_{1,2}}}}, \tag{25}$$

$$v = A\delta(x) + (1-A)\left(1 - e^{-\frac{x}{\bar{\gamma}_{R_{1,1}D_{1,2}}}}\right). \tag{26}$$

The PDF of u and v can be determined by differentiating their CDFs,

$$f(u) = \frac{\mathrm{d}}{\mathrm{dx}}\left(1 - e^{-\frac{x}{\bar{\gamma}_{SD_{1,2}}}}\right) = \frac{e^{-\frac{x}{\bar{\gamma}_{SD_{1,2}}}}}{\bar{\gamma}_{SD_{1,2}}}, \tag{27}$$

$$f(v) = \frac{d}{dx}\left(A\delta(x) + (1-A)\frac{e^{-\frac{x}{\overline{\gamma}_{R_{1,1}D_{1,2}}}}}{\overline{\gamma}_{R_{1,1}D_{1,2}}}\right) = A\delta(x) + (1-A)\frac{e^{-\frac{x}{\overline{\gamma}_{R_{1,1}D_{1,2}}}}}{\overline{\gamma}_{R_{1,1}D_{1,2}}}. \quad (28)$$

Transforming u and v to the frequency domain by using the moment generating function (M), expressed as

$$M(u) = \frac{\frac{1}{\overline{\gamma}_{SD_{1,2}}}}{\frac{1}{\overline{\gamma}_{SD_{1,2}}} - s}, \quad (29)$$

$$M(v) = A + (1-A)\left(\frac{\frac{1}{\overline{\gamma}_{R_{1,1}D_{1,2}}}}{\frac{1}{\overline{\gamma}_{R_{1,1}D_{1,2}}} - s}\right). \quad (30)$$

The PDF of the total received SNR can be found by multiplying $M(u)$ with $M(v)$, expressed as

$$f_Z(x) = M(u)\text{x}M(v) = A\left(\frac{\frac{1}{\overline{\gamma}_{SD_{1,2}}}}{\frac{1}{\overline{\gamma}_{SD_{1,2}}} - s}\right) + (1-A)\left(\frac{\frac{1}{\overline{\gamma}_{R_{1,1}D_{1,2}}}}{\frac{1}{\overline{\gamma}_{R_{1,1}D_{1,2}}} - s}\right)\left(\frac{\frac{1}{\overline{\gamma}_{SD_{l,2}}}}{\frac{1}{\overline{\gamma}_{SD_{l,2}}} - s}\right). \quad (31)$$

Using partial fraction expansion to expand the multiplication product term, we obtain

$$f_Z(x) = M(u)\text{x}M(v) = A\left(\frac{\frac{1}{\overline{\gamma}_{SD_{1,2}}}}{\frac{1}{\overline{\gamma}_{SD_{1,2}}} - s}\right) + \frac{1-A}{\frac{1}{\overline{\gamma}_{SD_{1,2}}} - \frac{1}{\overline{\gamma}_{R_{1,1}D_{1,2}}}}\left[\left(\frac{\left(\frac{1}{\overline{\gamma}_{SD_{1,2}}}\right)\left(\frac{1}{\overline{\gamma}_{R_{1,1}D_{1,2}}}\right)}{\frac{1}{\overline{\gamma}_{R_{1,1}D_{1,2}}} - s}\right) - \left(\frac{\left(\frac{1}{\overline{\gamma}_{SD_{1,2}}}\right)\left(\frac{1}{\overline{\gamma}_{R_{1,1}D_{1,2}}}\right)}{\left(\frac{1}{\overline{\gamma}_{SD_{1,2}}}\right) - s}\right)\right]. \quad (32)$$

Determining the CDF by transforming it to the time domain by applying an inverse Laplace transform to $F_Z(x)$, we get

$$F_Z(x) = A\left(\frac{e^{-\frac{x}{\overline{\gamma}_{SD_{1,2}}}}}{\overline{\gamma}_{SD_{1,2}}}\right) + \frac{1-A}{\frac{1}{\overline{\gamma}_{SD_{1,2}}} - \frac{1}{\overline{\gamma}_{R_{1,1}D_{1,2}}}}\left[\left(\frac{e^{-\frac{x}{\overline{\gamma}_{R_{1,1}D_{1,2}}}}}{\left(\overline{\gamma}_{SD_{1,2}}\right)\left(\overline{\gamma}_{R_{1,1}D_{1,2}}\right)}\right) - \left(\frac{e^{-\frac{x}{\overline{\gamma}_{SD_{1,2}}}}}{\left(\overline{\gamma}_{SD_{1,2}}\right)\left(\overline{\gamma}_{R_{1,1}D_{1,2}}\right)}\right)\right]. \quad (33)$$

Then, we can calculate the outage probability (P_{out}^{coop}) by integrating $F_Z(x)$ with respect to the given threshold (*th*),

$$P_{out}^{coop} = \left[1 - \exp\left(-\frac{2^{2th}-1}{\overline{\gamma}_{SR_{1,1}}}\right)\right]\left[1 - \exp\left(-\frac{2^{2th}-1}{\overline{\gamma}_{SD_{1,2}}}\right)\right] + \frac{\exp\left(-\frac{2^{2th}-1}{\overline{\gamma}_{SR_{1,1}}}\right)}{\left(\frac{1}{\overline{\gamma}_{SD_{1,2}}} - \frac{1}{\overline{\gamma}_{RD_{1,2}}}\right)}\left[\frac{1}{\overline{\gamma}_{SD_{1,2}}}\exp\left(-\frac{2^{2th}-1}{\overline{\gamma}_{R_{1,1}D_{1,2}}}\right) - \frac{1}{\overline{\gamma}_{R_{1,1}D_{1,2}}}\exp\left(-\frac{2^{2th}-1}{\overline{\gamma}_{SD_{1,2}}}\right)\right]. \quad (34)$$

B. Derivation for the 1R2D configuration

The CDF of the received SNR of a direct link (u) and the CDF of the received SNR of an indirect link (v) in the case of $1R2D$ are as follows,

$$u = \left(1 - e^{-\frac{x}{\bar{\gamma}_{SD_{1,2}}}}\right)\left(1 - e^{-\frac{x}{\bar{\gamma}_{SD_{2,2}}}}\right), \tag{35}$$

$$v = A\delta(x) + (1 - A)\left(1 - e^{-\frac{x}{\bar{\gamma}_{R_{1,1}D_2^*}}}\right). \tag{36}$$

Using the same method in the derivation of the $1R1D$ configuration, we get the following expression for the outage probability,

$$\begin{aligned} P_{out}^{coop} = &\left[1-\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SR_{1,1}}}\right)\right]\sum_{l=1}^{2}\left[1-\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SD_{l,2}}}\right)\right] + \sum_{l=1}^{2}\frac{\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SR_{1,1}}}\right)}{\left(\frac{1}{\bar{\gamma}_{SD_{l,2}}}-\frac{1}{\bar{\gamma}_{R_{1,1}D_2^*}}\right)}\left[\frac{1}{\bar{\gamma}_{SD_{l,2}}}\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{R_{1,1}D_2^*}}\right)-\frac{1}{\bar{\gamma}_{R_{1,1}D_2^*}}\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SD_{l,2}}}\right)\right] \\ &-\left[1-\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SR_{1,1}}}\right)\right]\left[1-\exp\left(-\left(2^{2th}-1\right)\sum_{l=1}^{2}\left(\frac{1}{\bar{\gamma}_{SD_{l,2}}}\right)\right)\right] \\ &-\frac{\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{SR_{1,1}}}\right)}{\sum_{l=1}^{2}\left(\frac{1}{\bar{\gamma}_{SD_{l,2}}}\right)-\frac{1}{\bar{\gamma}_{R_{1,1}D_2^*}}}\left[\sum_{l=1}^{2}\left(\frac{1}{\bar{\gamma}_{SD_{l,2}}}\right)\left(1-\exp\left(-\frac{2^{2th}-1}{\bar{\gamma}_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\bar{\gamma}_{R_{1,1}D_2^*}}\exp\left(-\frac{\left(2^{2th}-1\right)\sum_{l=1}^{2}\left(\frac{1}{\bar{\gamma}_{SD_{l,2}}}\right)}{\bar{\gamma}_{SD_{2,2}}}\right)\right]. \end{aligned} \tag{37}$$

C. Derivation for the 1R3D configuration

The CDF of the received SNR of a direct link (u) and the CDF of the received SNR of an indirect link (v) in the case of $1R3D$ are as follows,

$$u = \left(1 - e^{-\frac{x}{\bar{\gamma}_{SD_{1,2}}}}\right)\left(1 - e^{-\frac{x}{\bar{\gamma}_{SD_{2,2}}}}\right)\left(1 - e^{-\frac{x}{\bar{\gamma}_{SD_{3,2}}}}\right), \tag{38}$$

$$v = A\delta(x) + (1 - A)\left(1 - e^{-\frac{x}{\bar{\gamma}_{R_{1,1}D_2^*}}}\right). \tag{39}$$

Using the same method in the derivation of the $1R1D$ configuration, we get the following expression for the outage probability,

$$P_{out}^{coop} = \left[1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)\right]\sum_{l=1}^{3}\left[1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SD_{l,2}}}\right)\right]$$

$$+\sum_{l=1}^{3}\left\{\frac{\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)}{\left(\frac{1}{\gamma_{R_{1,1}D_{l,2}}}-\frac{1}{\gamma_{R_{1,1}D_2^*}}\right)}\left[\frac{1}{\gamma_{SD_{l,2}}}\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SD_{l,2}}}\right)\right)\right]\right\}$$

$$-\left[\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)\right)\left(1-\exp\left(-\frac{(2^{2th}-1)(\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}})}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)\right)\right]$$

$$-\left[\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)\right)\left(1-\exp\left(-\frac{(2^{2th}-1)(\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}})}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)\right)\right]$$

$$-\left[\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)\right)\left(1-\exp\left(-\frac{(2^{2th}-1)(\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}})}{\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)\right)\right]$$

$$-\frac{\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)}{\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}}\left[\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}\left(1-\exp\left(-(2^{2th}-1)\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{2,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{2,2}}}\right)\right)\right)\right]$$

$$-\frac{\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)}{\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}}\left[\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}\left(1-\exp\left(-(2^{2th}-1)\left(\frac{\gamma_{SD_{1,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{1,2}}\gamma_{SD_{3,2}}}\right)\right)\right)\right]$$

$$-\frac{\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)}{\left(\frac{\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}}\left[\left(\frac{\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}\left(1-\exp\left(-(2^{2th}-1)\left(\frac{\gamma_{SD_{2,2}}+\gamma_{SD_{3,2}}}{\gamma_{SD_{2,2}}\gamma_{SD_{3,2}}}\right)\right)\right)\right]$$

$$+\frac{\exp\left(-\frac{(2^{2th}-1)}{\gamma_{SR_{1,1}}}\right)}{\sum_{l=1}^{3}\frac{1}{\gamma_{SD_{l,2}}}-\frac{1}{\gamma_{R_{1,1}D_2^*}}}\left[\sum_{l=1}^{3}\frac{1}{\gamma_{SD_{l,2}}}\left(1-\exp\left(-\frac{(2^{2th}-1)}{\gamma_{R_{1,1}D_2^*}}\right)\right)-\frac{1}{\gamma_{R_{1,1}D_2^*}}\left(1-\exp\left(-(2^{2th}-1)\sum_{l=1}^{3}\frac{1}{\gamma_{SD_{l,2}}}\right)\right)\right]. \quad (40)$$

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