Fast Intra-Beam Switching Scheme using Common Contention Channels in Millimeter-wave based Cellular Systems

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***Abstract*—Millimeter wave (mmWave) cellular system has recently been introduced as an attractive approach for 5G mobile broadband communications. In the mmWave beamforming cellular systems, the user equipment (UE) can experience frequent service disruptions due to frequent switching among a plurality of beams if the UE follows the network controlled LTE handover procedures. In this paper, we shows how the mmWave beamforming cellular system can operate and which kind of new handovers UEs can experience. And we propose UE controlled beam switching mechanism based on contention based uplink channels. In this mechanism, UEs switch the serving beam to the target beam without random access delay using the pre-acquired contention based channels.**

***Keyword*—Beam switching, millimeter wave communication, millimeter wave cellular systems**

I. INTRODUCTION

Recently, as the growing number of smart phones and tablet PCs drives the increase of applications requiring much more traffic, the mobile data usage and traffic is more accelerated. According to [1], the high-definition video, sophisticated augmented reality and new types of games will be becoming major applications in the next decade which require 1000x bandwidth. However it is very difficult to satisfy the demand for bandwidth hunger applications with spectral efficiency enhancement because it has reached near practical Shannon limits. In addition, acquiring more spectrum below 6GHz cannot provide the capacities required because there isn't enough spectrum there. To meet 1000x requirements, approaches different from the existing methods have to be considered [2].

An attractive approach is to use millimeter wave (mmWave) spectrum for 5G mobile communication systems [3]. mmWave has experienced higher propagation losses such as path losses or return losses than bands below 6GHz. This characteristic reduces both of cell coverage and interference. However minimized interference enables dense deployments of small cells. Therefore, the total capacity can be scaled with the number of base stations (BSs).

Path losses at mmWave bands, meanwhile, can be overcome in use of massive MIMO (Multiple-input and multiple-output) technology in which antenna arrays consist of many active antenna elements. Nevertheless, the propagation losses have a negative effect on service coverage of the mmWave wireless communication systems. In this case, beamforming technology can be utilized to increase service coverage, expand cell capacity and minimize interference [4], [5]. Beamforming is an advanced technology in which a transmitting side transmits a plurality of beams in different directions and a receiving side receives a plurality of beams in different directions.

In the mmWave cellular systems using beamforming technology, a BS can forms a plurality of beams towards the desired users (UE). In this beamforming architecture, a new type of handover - beam switching within the same BS or among different BSs - can occur.

While multiple narrow beams increase network capacity, they also cause frequent beam switching even if the UE moves around within the same BS. If the UE follows the conventional network controlled/UE assisted handover procedures in Long Term Evolution (LTE) defined by the Third Generation Partnership Program (3GPP) [6], the UE experiences frequent service disruptions. In this paper, we propose simple UE controlled beam switching mechanism using contention based uplink channels.

The rest of this paper is organized as follows. Section II describes the architecture of the proposed mmWave beamforming cellular systems. Section III discusses the contention based intra beam switching mechanisms. Finally, we conclude our work in Section IV.

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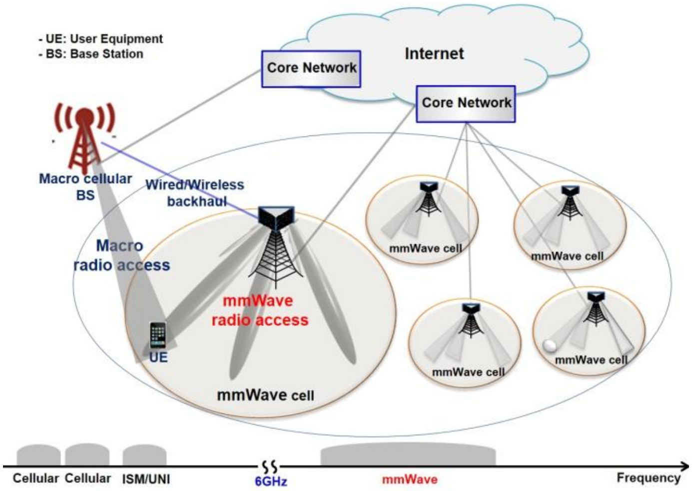

Fig. 1. mmWave based beamforming cellular systems.

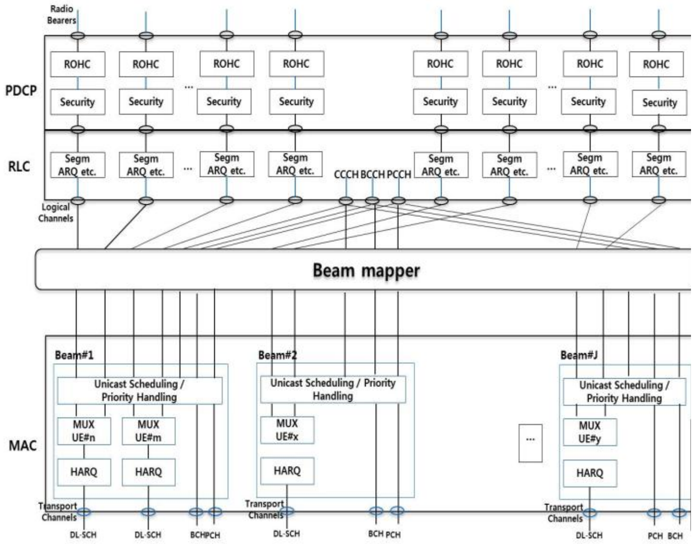

Fig. 2. The protocol architecture of mmWave based beamforming BS system.

II. MMWAVE BEAMFORMIG CELLULAR SYSTEMS

A. mmWave beamforming cellular system architecture

To meet the 1000-fold bandwidth requirements, the mmWave cellular system is one of the promising solutions [2]. First, the wide bandwidths for carrying bandwidth hunger applications are available at mmWave spectrum above 6GHz. Second, a number of picocell BSs with a plurality of directional beams can be densely deployed in the small areas due to the minimized mutual interference at the high frequency spectrum. Therefore, total capacity increases proportionally with the number of the BSs. Consequently, more available bandwidth at mmWave and capacity scalability deliver per-user data rate for supporting high speed data and high definition video transmission. The Giga Korea Project is a representative example to develop the mmWave based mobile communications systems to deliver Gbps broadband connection by 2020.

Fig. 1 depicts our proposed mmWave beamforming cellular systems which provide a kind of outdoor picocells and can be installed on existing street poles like lamp posts. In this architecture mmWave cells are overlayed in macro cellular networks or run as a stand-alone. We consider both of dual connectivity and stand-alone operation possible for future 5G networks. Thus, the UE supports different operation modes like 4G and 5G radio access and different coverage layers such as macro cells or mmWave picocells. In addition, a single common 5G core network is designed to support 4G and WiFi access in use of the network virtualization based on the distributed architecture approaches. These proposed unified systems enables a various types of connectivity, services, and use cases integrated.

In addition to achieving high per-user data rates, low latency is another key target for the proposed systems since latency minimization provides new business opportunities to the industry and performance improvement which the advanced networks require for fast coordination and transmission among different network entities [7]. Latency is determined by one round trip transmission to deliver the control signaling or data transmission. And low latency is achieved by the shorter transmission time interval (TTI) length. With the short TTI length data blocks has to be transmitted for a short time but in wide frequency range.

The TTI length of 200us is set for the proposed system. In case of LTE the total user plane (U-plane) delay is 4.8ms under the assumption of 10% Hybrid Automatic Repeat-reQuest (HARQ) Block Error Rate (BLER) [8]. Using the same LTE latency calculation model, the U-plane one-way access latency for the proposed system is given as 2.46ms. This one-way access latency is calculated as $T_{USER-PLANE} = 2.1 + P * 3.6$ where p is the error probability of the first HARQ retransmission and UE Processing Time of 1ms and eNB Processing Time of 1.1ms are considered. The minimum U-plane latency is expected to be 2.1ms when p equals zero. However, the U-plane latency of 2.46ms is more realistic when considering radio frame alignment.

B. Beamforming base station architecture

An mmWave BS is designed to consist of three sectors which form forty eight narrow beams. Each beam uses the same 1 GHz bandwidth in 28GHz band and support theoretical speeds up to about 3.3Gbps. In our systems, the uplink transmission timing of all the beams within a BS is also assumed to be synchronized as the cell coverage is relatively small due to properties of the ultra-high frequency. And each beam works like a kind of the small cell BS which has its own physical channels, transport channels, and logical channels.

While each beam within the same BS shares the same cell identity (Cell ID) which is unique within the network, it has the different beam identity (Beam ID) which is unique within only the BS. There is only the single radio resource control (RRC) [9] entity in a BS and therefore the same RRC signaling messages can be delivered to UEs through broadcast channels or shared channels per beam within the same BS. For example, although UEs associates with different beams, each UE receives the same Master Information Block (MIB) broadcast on Physical Broadcast CHannel (PBCH) per beam and the same System Information Blocks (SIBs) sent on the Physical Downlink Shared Channel (PDSCH) through the same RRC messages.

We show the proposed beamforming mmWave cellular system architecture in Fig. 2. The logical channels from radio link control (RLC) entity are mapped to the most proper beam including beam-specific medium access control (MAC) entities through the beam mapper which is newly introduced in the proposed mmWave beamformig cellular systems. Beam mapping has considerable effect on network throughput and depends on beam switching policy; network controlled UE assisted beam switching or UE-controlled beam switching.

- In case of network controlled UE assisted beam switching, beam switching is decided and initiated by the BS based on the measurement feedback information which the network asks the UE to measure the signal of the surrounding beams and report.
- In case of UE-controlled beam switching, the UE estimates the signal quality from each beam from the serving BS and the neighboring BSs and performs an appropriate beam switching procedures for selecting its target beam.

In our paper, we are just concerned about the UE-controlled beam switching which promises greatly increased scalability for the mmWave cellular systems.

Within each single beam, the unicast scheduler in MAC entity is responsible for scheduling the beam's radio resources utilized in the uplink and downlink whilst satisfying the required quality of service (QoS) for all active radio bearers within the beam.

III. CONTENTION BASED BEAM SWITCHING MECHANISM

A. Introduction of beam switching

In our proposed mmWave beamforming cellular systems, the initial camp on procedure is similar with the existing LTE camp on procedure except that the UE searches for both of suitable beams and cells and camps on the selected beam instead of the cell. The reason is that each beam acts like the single small cell BS in which its own physical channels are defined as shown in Fig. 2. The UE then performs the attach procedure in order to register in the tracking area of the selected cell. However, the location registration process takes place on cell level, not on beam level. The UE now continuously monitors and searches for the best beam/cell on which to camp.

In LTE, there are three kinds of handovers relying on whether the evolved packet core (EPC) entities that a UE is connected to are switched after the handover or not: intra-LTE, inter-LTE, and inter-RAT.

- Intra-LTE: An intra-LTE handover will occur within current LTE nodes either via the X2 or via the S1 (intra-MME and intra-SGW)
- Inter-LTE: Inter-LTE handover will take place toward the other LTE nodes that belong to the different pooling area (inter-MME and inter-SGW)
- Inter-RAT: Handover between different radio technology networks, for example E-UTRAN and GERAN/UIRAN

As mentioned in Section II, new types of handovers are

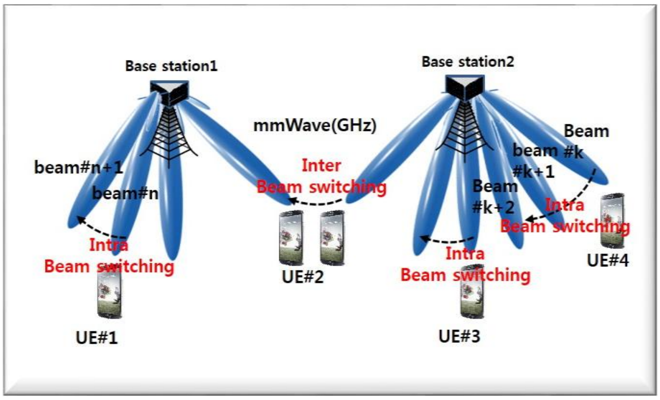

Fig. 3. The types of beam switching in beamforming cellular systems

required in mmWave beamforming cellular systems because a UE has the connection with a BS through the channels in the beams, not the channels in the cell. In other words, each cell consists of the multiple beams and there are separate physical channels per beam which transport control messages and user beam (serving beam) to the other beam (target beam) within the same serving BS or the BS different from the serving BS shown in Fig. 3. Two types of beam switching can occur:

- Intra beam switching: When a beam switching happens, the target beam is selected among the beams transmitted by the same BS which the serving beam belongs to.
- Inter beam switching: When a beam switching happens, the target beam is selected among the beams transmitted by the target BS different from the serving BS which the serving beam belongs to.

For instance, in Fig. 3, UE#1 and UE#3/UE#4 change the serving beams within Base station 1 and Base station 2, respectively. This is the example of intra beam switching. In contrast, UE#2 moves toward the target beam which belongs to the neighboring BS. In this case, inter beam switching is required. The inter beam switching is very similar with a kind of general LTE handover procedure above mentioned. In this paper, we are concerned about intra beam switching instances.

B. Problems in intra-beam switching

Our proposed mmWave beamforming cellular approach provides network throughput advantages up to over 100Gbps and the solution to the wireless spectrum shortage. However, this approach also has a few technical limitations to be overcome. Newly introduced interference is proportional to the number of the overlapped beams which share and reuse the same frequency band within a serving BS and neighboring BSs. Another problem is more frequent switching between beams because the cell coverage of mmWave beamforming cellular systems is relatively small due to the properties of high frequency band and beam area per beam is a little narrow in comparison with the LTE cell. When a UE moves around, the UE may experience more frequent switching between neighboring beams although the UE stays in the same BS.

In LTE handover, MME always instructs the UE to change the cell, i.e. network controlled handover. Therefore, the existing LTE handover procedure aims to get minimum latency in case of cell changes [10]. While this type of handover has the advantage of better traffic load balancing [11], it is not suitable for a rapidly changing environment and high user density areas due to the associated signaling delay [12]. In the proposed mmWave beamforming cellular systems, users experience rapidly changing beam environment because of multiple narrow beams and the limited propagation distances of mmWave beams. This environment at mmWave frequencies makes UE controlled handover schemes more attractive. This type of handover has the advantage of a short reaction time and is suitable for small cell systems [13].

Another beam switching problem is related to the handover procedures. In LTE handover a UE sends a measurement report according to the measurement configuration specified by RRC protocol entity in the serving BS. And the serving BS decides handover initiation depending on this measurement report. In accordance with handover decision algorithm, handover preparation and handover execution phases are performed. After the UE sends a handover completion message to the BS, the handover procedure is migrated into handover completion phase. In response to this completion message, the target BS notifies the serving BS to release all the resources utilized by the UE and the target MME to switch the path of the packet to the target BS. This mobility management is conducted in RRC entity in Layer 3.

Intra beam switching procedure has characteristics different from above the LTE handover procedure because any switching of the current LTE nodes is not required, i.e. the UE keeps the connection with the same serving BS. Therefore, handover preparation phase is not required and handover completion phase can be simplified to notify the serving BS the completion of intra beam switching. Only the beam switching decision and execution processes need to be carried out in handover decision and execution phase as in LTE handover procedure. In particular, the handover execution phase needs to be swiftly completed within the domain of single BS. Thus, efficient fast intra beam switching schemes are required.

C. *Contention based beam switching scheme*

During the handover execution phase, the UE is asked to connect to the selected target networks. In this phase, the LTE UE generally performs random access procedures for uplink transmission timing synchronization and UL allocation for the handover completion message [14]. This means that the increasing distance between the UE and the BS requires consideration of propagation delay. However, the problem is that it takes about 10 Transmission Time Interval (TTI) to complete these procedures as shown in [15], [16]. In the result, these procedures cause considerable service disruptions in the rapidly changing beam environments.

In the proposed mmWave beamforming cellular systems, the beam coverage is relatively small, i.e. under about 500 m and each BS can synchronize the UE uplink transmission timing between its own beams. Thus, intra beam switching can be done without UL timing alignment procedures. To enable the efficient and low latency beam switching, the UE

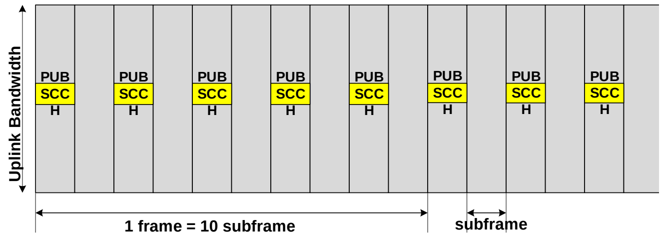

Fig. 4. Common contention based channels among all uplink beams, i.e. named Physical Uplink Beam Switching Control Channels (PUBSCCH).

sends Beam Switching Request MAC message in use of contention based access schemes.

In [17], the authors show that in LTE networks, unlimited use of contention based access is clearly useless since the collision probability over contention based channels increases rapidly. But limiting contention based transmissions on certain frames, for example voice frames, improve the satisfaction rate and the network throughput. In addition, in [18] authors proposed contention based uplink transmission in order to allow uplink synchronized UE to transmit uplink data without sending Scheduling Request message in advance. Thus, considering the relatively rich wireless resources at the high frequency bands and the smaller number of users per beam in mmWave cellular systems, contention based access schemes can be utilized for intra beam switching. As shown in Fig. 6, the limited number of uplink Resource Blocks (RBs) are dynamically scheduled on a per some subframe basis for beam switching. And the use of these RBs is constrained only for sending the uplink beam switching control element which is under a few bytes.

In our contention based beam switching scheme, some specific radio regions are defined as common contention based channels among all uplink beams, i.e. named Physical Uplink Beam Switching Control Channels (PUBSCCH), as shown in Fig. 4. This means that intra beam switching, i.e. contention based transmissions, does not interfere with other uplink transmissions for user data, i.e. contention free (CF) transmission. And the configuration for these common channels are broadcast by using system information block 2 (SIB 2) which is shared among the beams within single BS. In addition, a group of contention based radio network temporary identifiers (CB-RNTIs) is also defined in order to identify the UE within the single BS domain and a CB-RNTI is added into Beam Switching Request MAC PDU transmitted over contention based channels. Therefore, a UE can send the Beam Switching Request MAC CE through the serving beam without acquisition of PDCCH as in [17] since the UE can already know the CB grants by using the SIB 2 pre-acquired over the previous or current serving beam.

D. *Fast intra-beam switching scheme*

In this paper, we propose UE controlled contention based beam switching schemes done in MAC entity in Layer 2 as shown in Fig. 5. In our scheme, a UE measures RSRP (Reference Signal Received Power) parameter on beam-specific reference signal for each beam after the measurement configuration is provided to the UE in RRC-CONNECTED mode by the BS.

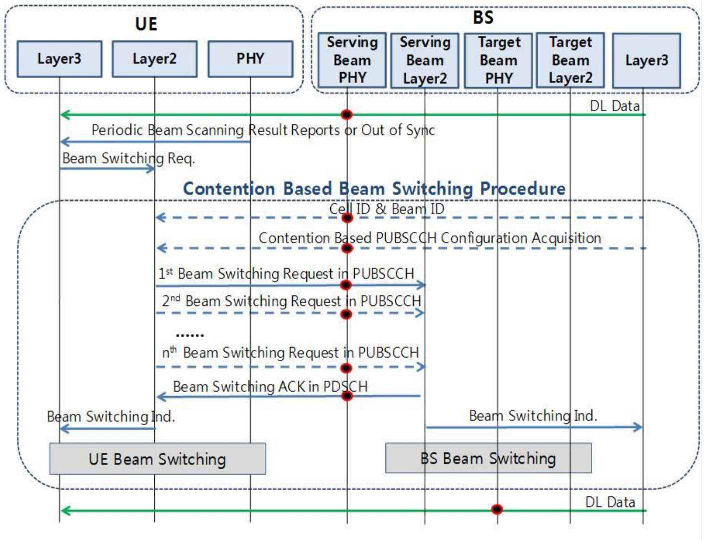

Fig. 5. The fast intra-beam switching: Communication success procedures.

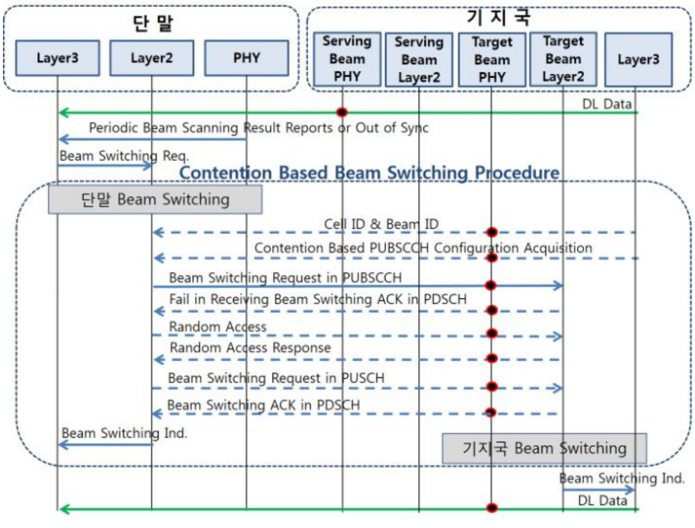

Fig. 6. The fast intra-beam switching: Communication failure procedures.

And the measurement results are managed by the RRC entity in the UE instead of the serving BS. Considering the rank of RSRP from the entire candidate beams along with serving beam, beam switching decision is made by the UE if the RSRP of any candidate beams within the serving cell meets the pre-defined threshold.

In the following handover execution phase, connection needs to be re-routed from the serving beam to the selected target beam by sending Beam Switching Request message to the serving BS. Using the contention based uplink channels as described in Section II-C, the UE transmits this control message through PUBSCCH without monitoring PDCCH. This is possible since the UE already acquires UL grants through the PUBSCCH configuration in the SIB. Then the UE starts the Beam Switching timer. This timer is stopped only when the Beam Switching ACK MAC CE is received through PDSCH. Whenever this timer reaches its time-out values, the UE retransmits the Beam Switching Request message. Due to a collision in PUBSCCH, the UE may fail in successfully receiving the Beam Switching ACK MAC CE within the specified time interval. The collided UE starts above the process again based on the uniform backoff algorithm in LTE [19]. However, the backoff indicator parameters which define the upper limit for a random backoff period is controlled by the UE, not by the BS.

After receiving Beam Switching Request MAC CE, the MAC entity on the BS site corresponding to the serving beam notifies the beam mapper and the RRC entity about the beam switching request. The beam mapper commands the UE to switch the serving beam to the target beam by sending Beam Switching ACK MAC CE through PDSCH in the serving beam using the same CB-RNTI in Beam Switching Request MAC CE. After the MAC entity in the UE sends Beam Switching Indication message to the RRC entity for beam switching completion, the UE and the beam mapper changes the serving beam to the target beam in the following subframe. Then, the UE can receive the packets through the target beam using the same C-RNTI used in the serving beam.

If the UE fails in intra-beam switching despite of a number of random backoffs, the UE transmits the scheduling request (SR) message through random access as shown in Fig. 6. The random access is necessary for applying for uplink resource grants for sending the Beam Switching Request message. It will take 2.8ms to complete this procedures in the best. Although this channel access latency is faster than that of LTE random access which provides about 14ms, it has significant impact on capacity decrease in rapidly changing beam environments.

IV. Conclusions

In the mmWave beamforming cellular systems, a plurality of beams causes frequent beam switching even if the UE moves around within the same base station. If the UE follows the network controlled LTE handover procedures, the UE experiences frequent service disruptions. In this paper, we shows how the mmWave beamforming cellular system can operate and which kind of new handovers UEs can experience. And we propose UE controlled beam switching mechanism based on contention based uplink channels. In this mechanism, UEs switch the serving beam to the target beam without random access delay using the pre-acquired contention based channels.

Acknowledgment

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