Another cell size reduction of LTE network

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***Abstract*— This paper proposes a new small cell network named Virtual Single Cell (VSC) network, besides one which the 3GPP studies, that is the macro-cell network enforced with small cells on very busy area. The VSC is applied to small cells which are contiguously deployed in campuses and belt-shaped service area along roads. It adopts EPON (Ether Passive Optical Network) for cost-effective backhaul network to accommodate large number of BSs (Base Stations) in dense small cell network. The VSC network offers reservation-based short gap handover. Each UE (User Equipment) is placed in an LMC (Logical Macro Cell) which consists of a few numbers of adjacent cells around the cell with a target UE. The handover in an LMC is directly triggered to a target BS using the reserved Schedule Request (SR) signaling on PUCCH (Physical Uplink Control Channel) of the 3GLTE based protocol. The LMC is also handed over following move of the target UE to enclose it in LMCs. The concatenated cells in LMCs for each UE can be regarded as a VSC allowing short handover gap. Handover resources like an SR code for handover triggering are prepared before handover action. Control signals and downward packets used in handover are multicast with EPON to every BS in each LMC. The overhead to achieve VSC is not necessarily large taking advantage of multicast over EPON. Packet transfer sequence integrity is maintained using sequence numbers in UE on handover not delivered through backhaul.**

Keywords— Small cell; virtual single cell; 3G-LTE; PON; fast handover

I. INTRODUCTION

The traffic of the mobile network is reported to have rapidly grown, and to continue here after [1]. The mobile network had cast off its services from the cellular phone base to the IP (Internet Protocol) base communications. As a matter of fact, when we go out to town, we see far more people handles wireless terminals today than the past in the cellular phone age. Users today can operate smart device for themselves with the automated servers on the Internet without any care for the callee, though calling by cellular phone needs human callee. Like that, mobile communications without direct human operation will increase in future, and the traffic of the mobile network will surely increase when M2M (Machine-to- Machine) communications become fulfilled [2]. In M2M, the information itself to be sent may not always be important. For example, infrared movie around walker in night might be continuously sent to cloud data center just to keep crime off.

For these tendency, small cells [3] have been becoming more and more necessary in the wireless network. Small cells boost up network throughput with increased number of cells. 3GPP (Third Generation Partnership Project) has announced standardization of heterogeneous network with small cells [6] to digest the rapid growth of IP traffic. Small cells are placed on very busy spots which can ordinarily happen at downtown and around railway terminals.

In addition to abovementioned use of small cells, another small cell networks will be allowed in areas like campuses where Ethernet LAN (Local Area Network) is deployed at present or on roads where more public terminals exist than other off road area. They can provide large capacity due to radio resource reuse in space domain, and higher frequency which is inevitably used in future fits small cells since its nature shows straight forward propagation and large loss in rain.

This paper proposes a new small cell networks with cost effective backhaul network to accommodate large number of BSs (Base Stations) and allowing short handover gap. This paper, however, discusses from the view of network control more than wireless interface, supposing high frequency radio features.

II. LARGE CELLS VS. SMALL CELLS

Today, mobile networks ordinarily use macro-cells. If the cell size is similarly reduced as shown in Fig. 1, the network capacity will increase in inverse proportion to the area size of cells, since number of cells in a service area also increases in the same way while the capacity of each cell is independent to the cell size if the band size is the same regardless to cell size.

Here, we examine how the features of the macro-cell networks can affect to cell size reduction.

Adaptability: In fact, networks only with small cells are inefficient and inhibitive. Macro-cell network needs small number of cells, and cost effective to cover large service areas.

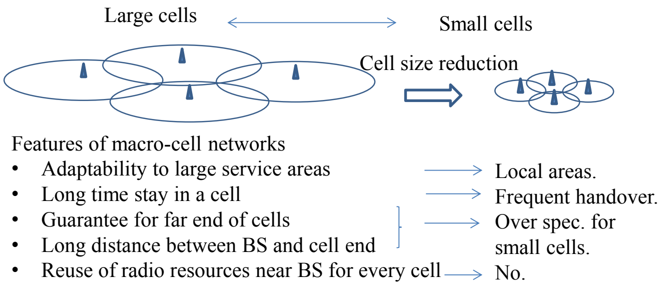
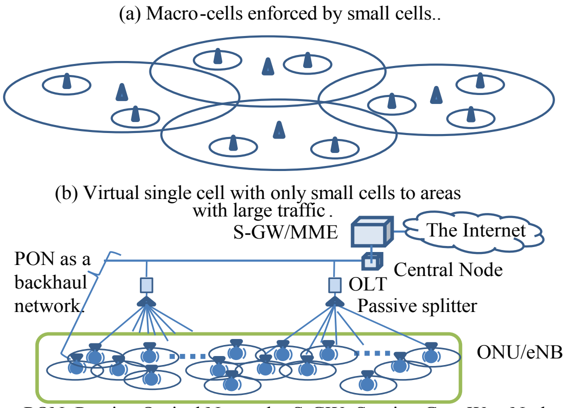


Fig. 1 Cell size reduction and its effects.



PON: Passive Optical Network, S-GW: Serving Gate Way Node, MME: Mobility Management Entity, OLT: Optical Line Terminal, ONU: Optical Network Unit, eNB: evolver NodeB

Fig. 2 Possible small cell use in future.

On the contrary, in small cells, number of cells becomes large and network facilities like backhaul also become large. This means new huge investment to respond increase of traffic with small cells. Still worse, network with only small cells are inefficient, since heavy traffic attacks to some cells though only little traffic rises in some other cells. Thus, macro-cells are widely used and some busy spots should be covered with small cells to offload the traffic of macro-cells as seen in 3GPP studies. In addition, there are some zone larger than spot where no few traffic can appear. In this case, small cell network similarly reduced from macro cell network will be able to exist as a local cellular network.

- Mobility support: In macro-cells, UE (User Equipment) can stay in a cell for rather long time, and thus, handover gap need not be seriously cared. However, in the reduced cells, handover gap should be negligible since handovers frequently happen.
- Distance care: Long distance propagation, and large multipath delay are reflected in macro cell protocol. On the other hand, the propagation distance is very short in small cell network. Thus, in small cell network, this feature should be utilized.
- Cell-by-cell reuse of radio bands: The same radio band can be shared near BS in every cell of the LTE-based macro cell network, since radio power can be reduced so as not to reach far. However, in smaller network, power down to enclose radio power near BS will be inhibitive since radio power in small cell network is already small. This inefficiency due to no repeatable use in small cell network should be cared.

III. VIRTUAL SINGLE CELL (VSC) NETWORK

Considering above discussions, use of small cells in future network must be those shown in Fig. 2. One is studied in 3GPP as a target of the LTE advanced, which is macro-cell based mobile network enforced with small cells situated at busy spots. The other is a virtual single cell (VSC) network where small cell are concatenated to allow cell-to-cell move of UE, of which handover gap is expected to be small enough as if UEs stays in a single cell. We present the VSC net hereafter.

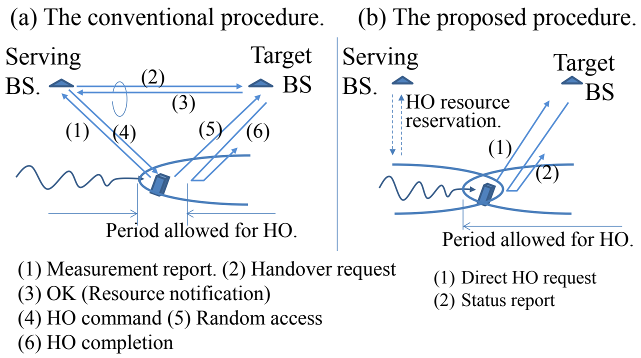


Fig. 3 Handover procedure comparison.

A. *Fundamental configuration*

1) Use of PON (Passive Optical Network): One of the big problems of small cell networks is economy. BSs themselves must be inexpensive like those for 802.11 WLAN (Wireless LAN). However, their backhaul facilities must be large since number of BSs is large. Thus, in order to connect large number of BSs, we believe PON will be essential for the back haul network as shown in Fig. 2(b). PON can cost-effectively accommodate large number of users as the basic facility of FTTH (Fiber-To-The-Home) offering the Internet access to home users as the last mile [15]. From the economical point of view, it is desirable to make full use of existing PON standard rather than to enact new private PON specification for mobile backhaul. We focus on EPON (Ethernet PON) that is widely used as an IP access means.

2) Synchronous BS operation: In order to make use of small cell, BSs of the proposed network are synchronously operated. This operation and short distance between BS and cell end can be used to achieve short handover as described later. This synchronization can be supported by accurate clock given by EPON for TDM (Time Division Multiplex)-based upward transfer and this accuracy is maintained by periodical ranging process to check round trip propagation delay between OLT and ONU (Optical Network Unit).

3) Use of millimeter wave: About use of radio resources in the small cells in future, high frequency radio band like millimeter wave which fits small cells will be used and forgives abundant of radio resources. The cell by cell orthogonality must be based on FDM (Frequency Division Multiplex). In this case, radio resource efficiency is not good compared to macro-cell since reuse of same resource near BS cannot be applied. However, enhanced repeatable reuse of radio band among cells taking advantage of small cells should cover the demerit.

B. *Handover Mechanism of VSC*

Needs of new handover method: Figure 3(a) depicts the abbreviated concept of the conventional handover procedure which is used in the LTE networks [4]. In fact, the conventional method is effective in LTE systems, since they use high speed link between eNBs (Evolved Nodes B)

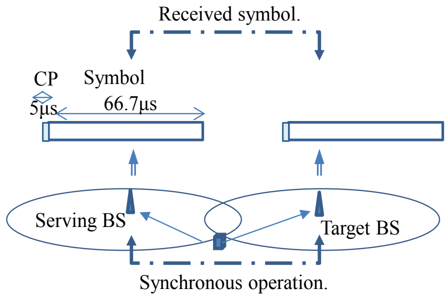


Fig. 4 Direct signaling to the target BS on synchronization.

providing functionality of Base Station with packet transfer control.

Thus, this procedure cannot allow short handover time for the proposed small cell network since it is assumed to use PON for the backhaul network. PON draws large latency in communications. In fact, one of the dominant causes of the large handover gap in the conventional method is due to communications through backhaul network.

1) There is another reason why the conventional procedure is not adequate to small cell network. Figure 3(a) also shows very narrow handover period in the conventional system. Handover should be finished during stay in the overlapped area of two cells. After the detection of radio wave from the target eNB, the target UE should ask handover request to the serving eNB. Thus, the handover should finish in the area where radio wave of the serving eNB can be used. This area must be very narrow, since in small cells radio power sharply decrease due to use of beamforming of MIMO (Multiple-Input and Multiple-Output).

The need of backhaul communication on handover is rooted in need of control by the serving eNB. No communication path to a target eNB exists before handover in OFDM (Orthogonal Frequency-Division Multiplexing) system, though UE can communicate with neighbor eNBs since it can interpret channel codes of the neighbor eNB in parallel to conversations with the serving eNB in case of 3G WCDMA (Wideband Code Division Multiple Access).

As result, the handover conversation including request and request OK should be conversed between the target eNB and the serving eNB. The serving eNB decides needs of handover based on the radio power measurement report from the UE, and sends the handover request to the target eNB, and receives Request OK including resources like a non-contention random access preamble from the target eNB, and then send forward it to the UE. The UE and the target eNB conduct random access procedure to make synchronization between them. For this, the preamble for random access should be set through the conversation between the serving eNB and the target eNB through backhaul network.

2) Direct handover tirggering to the target eNB: To avoid large handover gap, the proposed VSC network adopts direct handover trigger to the target eNB of which concept is shown in Fig. 3(b). This procedure does not need conversation through backhaul network on handover.

This direct interruption to the target eNB without random access can be achieved if eNBs and UEs in the network are synchronously operated and distance between eNB and UE is short. The serving eNB and neighbor eNBs can receive transferred symbols from UEs as shown in Fig. 4, if they arrive in CP (Cyclic Prefix) time. This condition can be achieved since eNBs are synchronously operated as above mentioned and all cells are small enough. In PON, upward data transmission is based on TDM as shown in Fig. 5(b). PON allows about 10 ns (nano seconds) frame gap of the TDM which is far smaller than about 5 micro seconds of CP period allowing multipath delay in 3G-LTE.

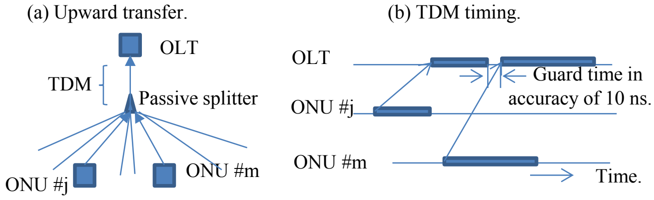


Fig. 5 Use of PON for backhaul network.

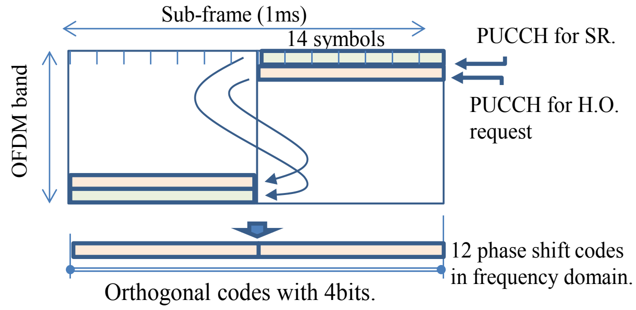


Fig. 6 PUCCH on OFDM band for uplink.

In addition to quick handover, the direct handover triggering allows large delay of the handover start, since handover can be achieved during the stay in the target cell, though large handover gap occurs, since the hand over request can be emitted during stay in the cell of the target eNB.

Considering adoption of 3G-LTE protocol, SR (Schedule Request) signal can be used for the handover triggering to the target eNB. SR signal is one of the signals on PUCCH (Physical Uplink Control Channel) and is originally used for a resource allocation request for packet transfer from UE to eNB when UE needs upward packet transfer after cease of packet transfers.

One modification from the original 3G-LTE protocol is use of additional PUCCH for the handover request as shown in Fig. 6. The prime PUCCH used for the original functions is located in the most outside resource blocks of the upward OFDM band, and the additional PUCCH for the handover trigger can be located to the next of the prime PUCCH as shown in Fig. 6. On 3G-LTE specification, PUCCH can be further added in the next of the first PUCCH, when large number of SR codes are needed due to large cell size and large number of UEs in each cell. In small cell networks, number of terminals in each cells is small enough to avoid use of additional PUCCH as the original functions.

Each SR code takes one of 12 phase shifts if frequency domain and one of four orthogonal bit codes. Thus, the number of independent orthogonal codes can be numerically 48, however some of codes is said to be used to avoid mutual interference [4].

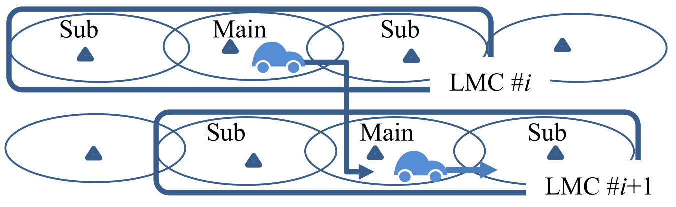


Fig.7 Virtual single cell control.

3) Tracking of UE movement: The quick handover in an LMC should follow the movement of UE. The mechanism is shown in Fig. 7. Here, the main denotes the serving cell and a set of sub does the candidates of the handover target. The sub eNB which detects arrival of UE with the handover trigger announces the construction of a new LMC to the neighboring cells. The eNB of the former main cell should downgrade itself to the sub eNB of the new LMC on receiving the announce. By conducting LMC tracking like this, the target UE is always captured within the shifting LMC by keeping the UE at the center of LMC.

4) Saving of reserved handover resources: In fact, reservation minimization of handover resource is the key so that the proposed handover procedure may be used. SR signal codes are reserved to each UE to allow the proposed handover, and downward packets should be reserved in the target cell together with the serving cell. Usually, the serving cell cannot detect moving direction of UEs, thus those handover resources should be reserved in handover target candidates. Usually, many candidates exists around the serving eNB, and overhead to do the small gap handover becomes large if the reservation is achieved to all of candidates since the use is only one of them. Thus, the reservation range should be minimized.

The minimization of handover resource reservation is application oriented. In case of small cells along roads, handover candidates exists only back and forth of the serving eNB, though only at crossing, the reservation should be done to eNBs of every direction. In other application, campus net, there can be many eNBs around one. However, major movement of UEs is anticipated. Those must be along corridors or passages.

5) Handover gap evaluation: Figure 8 shows comparison of handover time in the critical path between 3G-LTE based handover and the proposed one. In this figure, number in the parenthises indicates procedures of the same number shown in Fig. 3. In the proposed network, it takes 13.5ms (milli seconds) for handover period while it takes 34ms in LTE over PON. The proposed procedures is equivlent to one which removed from the 3G-LTE base. Our proposed procedure reduces handover period at 40 % and fast handover is established. In this calculation, we assume the following network parameters; PDCCH to target UE to allocate the data transfer happens every 5ms, processing time like getting resources for random access to target eNB and time from PDCCH to PUCCH are is 4ms the same that of hybrid ARQ (Automatic Repeat reQuest) after the data transfer. The period PON slots to each ONU happens in every 4ms. Here, we show rough evaluation of improvement of in handover gap

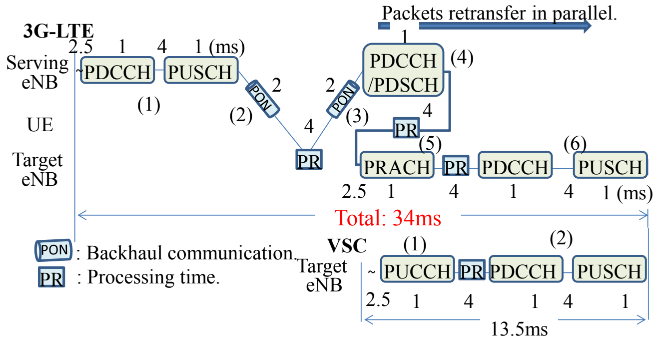


Fig. 8 Comparison of handover periods.

reduction. In this calculation, we assume the following network parameters; PDCCH to target UE to allocate the data transfer happens every 5ms, processing time like getting resources for random access to target eNB and time from PDCCH to PUCCH are is 4ms the same that of hybrid ARQ (Automatic Repeat reQuest) after the data transfer. The period of random access and SR interruption can happen every 5ms. PON slots to each ONU happens in every 4ms.

IV. EPON SUPPORTING VSC OPERATION

A. Fundamental transfer over PON

The followings are typical transfers for the VSC control and EPON adaptability to each. There can be five types of transfer in PON for the VSC system to handle LMC as shown in Fig. 9.

Figure 9(a) shows registration report transfer in an LMC. One of the eNBs which got registration request from an UE should become the main eNB of the LMC for the UE and should announce start of the LMC operation to the cells in the LMC over multicast. The multicast address should be the ID of the ONU on the main eNB of each LMC. Unlike unicast communications between the OLT and an ONU, the multicasts to an LMC from the ONU of the main eNB should be first unicasted upward to the OLT and then be resent as downward multicast to the LMC with multicast ID designating the center eNB of the LMC. The neighboring eNBs included in the LMC that receive the announcement should pick up messages to the

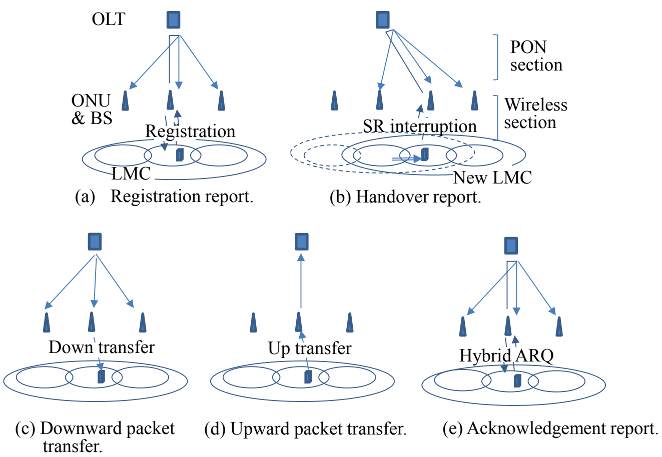


Fig. 9 Transfer type classification for PON.

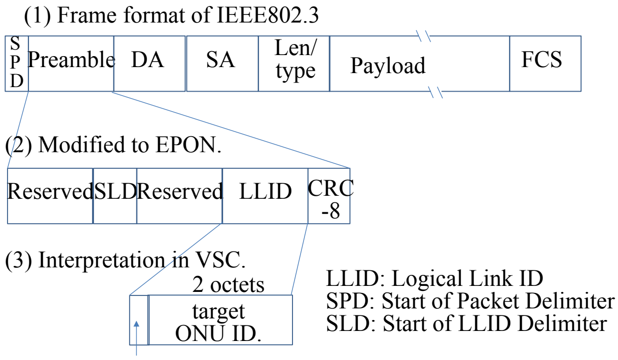


Fig.10 Frame and ONU ID as a transfer address.

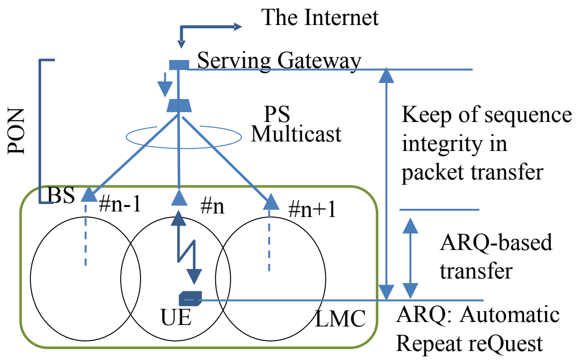


Fig. 11 Fragmentation and numbering.

main eNB as the sub eNBs of the LMC.

Figure 9(b) shows a handover report within an LMC. When an UE moves from a main eNB to one of sub cells, the eNB of the sub cell receives handover trigger from an UE. Then the eNB of the sub cell announces change of LMC. Every eNB recognizes the eNB designated by multicast ID to the center eNB of LMC. When the handover report comes from an eNB other than the old central eNB for the target UE, other eNBs can recognize the handover execution for the UE. Then, the degradation of the old main eNB is conducted, and the new LMC is reconfigured for the UE. No handover notification is needed from the old main eNB. The transfer type is as the same as registration from UE.

Figure 9(c) shows transfer of downward data. If multicast is once done over PON, the downward packet can be delivered to all eNBs in each LMC, where every eNB in the designated LMC stocks it for transfer over wireless interface to avoid retransfer from the serving eNB to the target eNB on handover. This should be a large merit using PON. On the other hand, the upward transfer uses point-to-point transfer as shown in Fig. 9(d) since the upward packets from UE are received by only center eNB, and the eNB of the center eNB just forwards them to the OLT over the PON.

When there is an eNB which accepts success of data transfer in wireless interface, the eNB should multicast the sequence number of frame successfully sent in wireless interface as shown in Fig. 9(e). This multicast is targeted at the same LMC as the sender. This multicast is used for discarding pre-stocked data at sub eNBs, and is an increase of backhaul communications in VSC system in comparison to the conventional LTE system.

In these major transfer modes, no point-to-point communication exists from an ONU to another ONU via OLT, though this type of communications are known as X2 interface communications and be ordinarily used in the conventional LTE system. So we can omit this type of communication in PON. All the communication among related cells in LMC can be done by the multicasting with the ID of the main eNB of each LMC.

Figure 10 shows a frame format of EPON for a start point for discussion. In EPON, LLID (Logical Link ID) in preamble field borrowed from IEEE802.3 is used to designate a target ONU. The most left bit of 2 byte LLID indicates broadcasting or point-to-point transfer and remain bits of LLID do each ONU. ID for downward transfer indicates a destination ONU, and one for upward does a source ONU since the destination of upward transfer is only OLT.

In VSC, multicasting should be the fundamental function to control LMC since the same message should be exclusively sent to each of eNB included in the same LMC. However, EPON does not provide multicast. Thus, the broadcasting ID is changed to multicast in the VSC system as shown in Fig. 10. When broadcasting is really necessary, we can use special ID that designates broadcast. For example, ID of all ‘1’ in every bit can be used like the broadcast address on Ethernet.

B. Sequence Integrity maintenance on Handover

Packet transfer network should provide sequence management mechanism in order to keep the correct packet transfer. In VSC, the Serving Gate Way node (S-GW) serves fragmentation and numbering for downward transfer, and UE does for the upward transfer as shown in Fig. 11. The downward packet from the Internet is multicast to the target LMC. At the wireless interface, the eNB and UE transmit frames in sequence adopting hybrid ARQ scheme.

In the data transfer, the sequence number notification at every transfer through the backhaul network and the sequence number synchronization among eNBs in each LMC are an ideal and fundamental concept in the VSC mechanism. Packet transfers with incorrect sequence happen if this procedure is skipped, and otherwise large packet transfer delay can happen if the sequence number notification through the backhaul network is enforced even on handover, and this makes effective data transfer rate low.

The sequence management can induce problem on handover in VSC, since large latency occurs to share the exact sequence number through the communication with PON. However, the latency can be neglected if the sequence number in the target UE is used instead of sequence number notification through PON. Status reports are exchanged between the eNB and the UE just after handover before the restart of packet transfer as shown in Fig. 12. In Fig.12(1), handover from eNB #*i* to eNB #*i*+1 happens just after the transfer of packet D2 and however, D2 acknowledgement notification to eNB #*i*+1 is delayed. Then, eNB #*i*+1 does not know success of the D2 transfer. However, the status report on PUSCH just after the handover can notify the success of the D2 transfer. However, the upward transfer can induce double

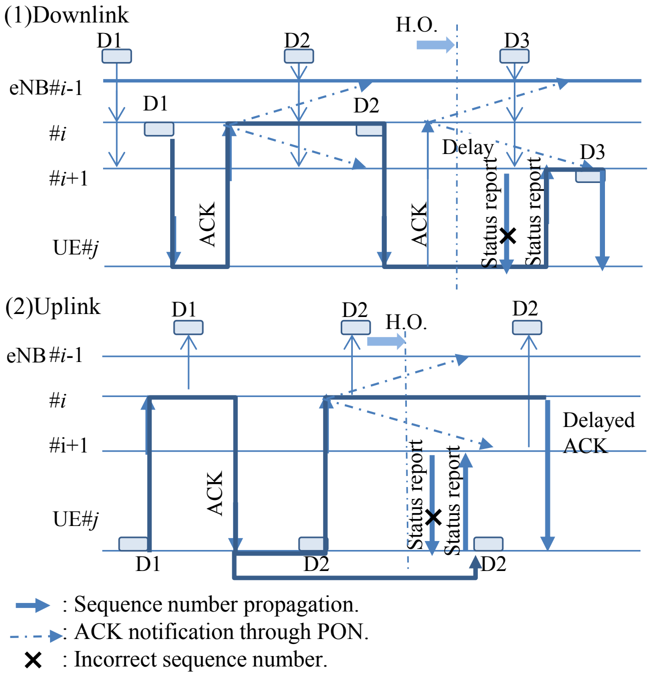


Fig. 12 UE-dependend sequence notification.

transfer of the same packet as shown in Fig.12(2), The downward status report on PDSCH (Physical Downlink Shared Channel), just after the handover is not always good since the notification from eNB #*i* to eNB #*i*+1 may be delayed due to the large latency of PON. Thus, UE chooses the most advanced sequence number among ACK form eNB#*i*, status report from eNB #*i*+1 and that in UE.

As result, the sequence number problem is on double transfers of the same frame. However, this is allowable in IP communications, though it induces inefficiency.

V. Conclusion

This paper has presented a possibility of a new type of small cell network which uses only small cells and can be applied in some local areas where large traffic exists. Small cells are contiguously placed to support mobility in the service area. The following are essentials of the network; (1) Use of PON for backhaul network, (2) Grouping of cells around a target UE, (3) Reservation of handover resources like interruption code in each group of cells, (4) Synchronous operation in the network, (5) Use of high frequency like millimeter wave. 3GLTE protocol can be adopted in the network with little modification. High throughput will be able to be obtained when millimeter wave is used with abundant radio resource. PON for backhaul network can be bottle neck of throughput, however, this will be dissolved with parallel use of PON. There are still many issues remained to be more deeply studied and radio technology anticipated use of higher frequency has not been cared. We hope this paper stimulates studies on this type of wireless network.

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