Handover and congestion relief in MM-MAN; Mobile Multimedia Metropolitan Area Network

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ABSTRACT - This paper presents the capability and challenge of a unified micro-cell-based network named MM-MAN (Mobile Multimedia Metropolitan Area Network) in providing multimedia communications to the fast terminals like those on vehicle-move. Micro-cellular network can offer rich radio resources due to high reusability of radio resource in space domain, and however, drags two major drawbacks for full scale mobility on surface; disturbance of smooth packet transfer to fast terminals due to the frequent handover and local traffic sensitivity triggering congestion. The authors have already proposed MM-MAN with the capability of maintaining smooth packet transfer to fast terminals in spite of frequent cell-to-cell move and also presented conceptual solutions for the local congestions. This paper presents a method to liberate this local congestion meanwhile still allowing high-bit rate packet transfer to fast moving terminals on network along cascaded micro-cells with Pico-cells. By the numerical analysis, we realize that the number of MTs served in the micro-cell increases 1.5 times if a Pico-cell is added.

I. INTRODUCTION

The authors have been studying a unified micro-cellular network named MM-MAN (Mobile Multimedia Metropolitan Area Network), aiming that the network can become a candidate for the 4G system. Micro-cellular systems which allow high degree reuse of radio bands in spatial aspect will become a mainstay in the 4G mobile system, since it is able to offer large volume of radio band for multimedia communications.

The drawbacks, however, should be overcome in micro-cellular networks in order to make use of their advantage in a real system. One is disturbance of smooth packet transfer due to the frequent handover, and the other is vulnerability to local congestion. Concentrated traffic of vehicles can easily happen in a cell like crossing on a road.

This paper proposes a chain of micro-cells each of which contains Pico-cell to release the local congestion. It also evaluates the effect of Pico-cell in a micro-cell from the view of performance.

II. THE UNIFIED MICRO-CELLULAR NETWORK

The authors have proposed a unified micro-cellular network for future mobile age. It is named MM-MAN, of which network image is described in Fig. 1. The profitable demands for mobile multimedia communications will first arise in the metropolitan area where businesses activities are animated either in their office or in their moving way where many people are equipped with high-tech devices. Extension of the private LAN (Local Area Network) of users to cellular network must be one of the advanced services. LANs of many organizations are logically overlapped and work as the virtual LAN of each organization. In the extended LAN, users can enjoy the same IT environment of the office LAN that users even though moving at vehicular speed. VPN (Virtual Private Network) tunnel is established among moving terminals of the same organization and between the moving terminals and the original office LAN [1]. Voice or video conference and document downloading and exchange during driving will be conducted.

A large number of micro-cells is scattered widely in the metropolitan area. For street-covering micro-cells, special functions need to be equipped to promise that fast terminals are all provided smooth connections. For micro-cells in the other area than the streets, fast handover support is not necessary because they are seen as hotspots.

![MM-MAN Concept](image)

Fig. 1 - MM-MAN Concept
III. DRAWDOWKS OF MICRO-CELLULAR NETWORK

The diameter of micro-cells of the unified micro-cellular network will be from about 100m to 500m. Frequent handover and local congestions will happen as shown in Fig. 2 and as follows.

A. Frequent Handover

Handover for vehicles driving at the speed of 100km/h happen from every 2 second to every 20 second. Handover conversation is necessary at the boundary of the cells on handover between old cell and new cell in very short period at handover. In order to allow soft handover, the overlap of cells becomes very large. This means the effect of micro-cellular network decreases. New mechanism of the handover of the micro-cellular network will be required.

B. Local Congestion

MTs move randomly on the way. Thus, many vehicles happen to gather in some of micro-cells. It can trigger communication traffic congestion. For example, vehicle’s speed-down happen before a cross section due to the control by traffic lights.

We realize there are two types of congestion after observation of vehicular traffic. One happens at the cross section of roads. This congestion can be called the space-dependent congestions, since it happens in the special cell at any time. The other occurs in a series of micro-cells on the road at the busy hour of traffic. This congestion can be called the time-dependent congestion, since it can happen at any cell in busy hour.

Local congestion should be managed in each micro-cell in the micro-cellular system, though such kind of congestion was not much critical in the conventional macro-system since it can be managed with the resources in a wider area.

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Figure 3 depicts the observation of road traffic. Number of vehicles in the assumed micro-cells along road in the range of 10km as shown is counted at the day time, and late afternoon. Here, diameter of micro-cell is assumed to be 100m. Figure 4(b) depicts the time-dependent congestions.

The horizontal axis indicates the number of vehicles in each micro-cell, and the accumulated number of corresponding cells is shown in the vertical axis.

In the time other than rush hour, the traffic of cells of more than 50% in number is under the maximum capacity. However, 30% of cells including cells of cross sections face lack of resource. Here, assume that the network offers 48% of the maximum channel speed (100Mbps)[3], and the speed is shared by active terminals with a speed of 20Mbps.

This percentage comes from the strategy mentioned later which overcomes the frequent handover problem. In this assumption, the number of MT on the line is 2.4 on average, and the number of MT accommodation is 12 if 20% of terminals in each cell are on the line.

The rush hour traffic is 2 or 3 times larger than ordinal traffic. Congestions occur almost all over the cells in case the radio resource is fitted to the small traffic. On the other hand, the more resource fitting for the rush hour is provided which is wasted in the ordinal hour and this period is dominant every day

IV. HANDOVER SOLUTION FOR FAST MOVERS

Smooth and continuous packet transfer to fast terminals in spite of frequent handover can be achieved by LMC (Logical Macro-cell) and parallel polling [2] and [3] as follows

A. LMC concept

Combining several micro-cells and configuring a virtual single cell are one of the essentials for the solution to avoid frequent handover in micro-cellular network. The LMC consists of several adjacent micro-cells, and is statically configured with a central micro-cell at the center in each LMC as shown in Fig. 4 (a). Every MT (Mobile Terminal) belongs to one of LMC at any instant, and the backbone
network connecting BSs (Base Stations) directs controls over target MTs assuming they stay in one of micro-cells of the corresponding LMC.

B. LMC Support by PON

Passive Optical Network (PON) as the terrestrial network plays an important role to support the LMC system as reported in [4]. Broadcasting capability of PON allows the packet multicast to each LMC. The central node stands on an OLT (Optical Line Terminal) which is at the end of trunk fiber. At the other end of trunk fiber, there is a passive splitter at which many branch fibers are connected. BS (Base Station) on ONU (Optical Network Unit) is at the other end of each branch fiber. The downstream packets are broadcast to every ONU. The upstream packets are carried on TDM-base.

Data packets destined to the target MT and control information are multicast to every BS in the corresponding LMC over PON. Since the same information is provided to every BS in each LMC, each BS can control MT as if it owns MT even though in fact it may be connecting in other micro-cell in the LMC.

PON is suitable for the terrestrial network of the micro-cellular system from the economic point of view PON can accommodate many BSs efficiently, and become available in metropolitan area since it penetrates there as the FTTH (Fiber-To-The-Home) facilities.

C. Parallel polling in LMC neglecting cell-to-cell move

To neglect cell-to-cell move of MT in each LMC, a set of the same polling is emitted to every micro-cell in the LMC where the target MT is assumed to stay in. The MT answers to only one of the micro-cells of the same LMC where it really stays and the packet transfer is executed in this micro-cell. Due to the parallel polling, the target MT can be handled at any cell in the same LMC. Cell-to-cell move before each packet transfer does not need to be cared.

The absence of the ACK for polling can be quickly detected with no carrier from terminals. This is because the cell size is small, and no hidden terminal exists since all the conversations in the wireless section are conducted under the polling control in each BS.

To allow the continuous parallel polling, every BS in the target LMC should operate almost synchronously. In order to do this, the polling acknowledgement (ACK) is multicast to every BS in the LMC through PON. Thus, PON which offers broadcasting is also important for this purpose.

The periodical cycle of the parallel polling is shown in Fig.5. The next cycle can start after the arrival of multicast ACK of the precedent parallel polling and data transfer. During the waiting period, parallel polling and data transfer can be carried to other mobile terminals.

D. Switch-over of LMC following terminal move

The LMC should follow the move of the MT beyond LMC boundary, though MT’s cell-to-cell move within an LMC can be neglected. For that purpose, LMC is switched over when polling ACK is received at any micro-cell other than one where the precedent ACK was received. The next adjacent micro-cell to which the target MT moves in is located as the central cell of a new LMC after detecting the present polling ACK. The switch-over of LMC is shown in Fig.4 (b).

Smooth packet transfer is required even when the target MT changes driving direction in a cross section. For that purpose, the number of micro-cells in an LMC for cross section of roads is increased to meet the direction change of
mobile users. Adjacent micro-cells over the crossed road are included in the cross section. Then, move of the target MT can be detected in the next micro-cell on the crossed road, and the switchover to the next LMC is achieved even to the crossed road.

Need of switchover of LMC for each move of mobile user to the next cell looks similar to the handover in the packet transfer of the ordinal micro-cells. The difference is that the switchover doesn’t have to be conducted before the first packet transfer in the new cell. Thus, the switch-over does not need to happen in the narrow boundary between micro-cells. The handover time now depends on the gap between two polling cycles.

E. Pico-cell in a micro-cell and traffic distribution

In order to overcome the offered traffic unbalance, small double-tier structure becomes an effective way to liberate load congestion. Pico-cell is installed within micro-cell as shown in Fig. 6(a). Base stations both of micro-cell and Pico-cell situate at the same position and their control functions can directly communicate each other. Thus, the co-processing can be easily achieved.

Figure 6 depicts the concept of handover between micro-cell and Pico-cell. The procedure is conducted under the active radio environment micro-cell and the corresponding Pico-cell. Every procedure is conducted under the active radio environment of the micro-cells. The communications are conducted on the polling base at any conversation corresponding to the phase A – D in Fig. 6 as follows:

Phase A: At the beginning of packet transfer in Pico-cell, the detection of radio power of Pico-cell is piggy backed on the polling ACK of the MT to the target micro-cell.

Phase B: Then, the BS of micro-cell indicates handoff to the BS of Pico-cell.

Phase C: The Pico-cell continues polling-based packet transfer for the MT.

Phase D: The BS of the Pico-cell indicates handoff to the micro-cell when it detects no ACK from the target MT.

The above-mentioned procedure allows continuous packet transfer except for the exit of the MT from the Pico-cell if the polling is regularly emitted. A series of polling skips a cycle in each Pico-cell at the exit from Pico-cell of MT. Polling based handover procedure principle is depicted in Fig.7. Polling error can happen in the bad radio conditions. In case of the exit, ratio of this skip is only about $10^{-4}$ if the diameter of Pico-cell is 50m, and if the MT drives at 100km/h. MT stays 1.8 sec. at a Pico-cell, and 6250 packet transfer cycles can happen in a second, in case the packet size is 2000 bytes and the channel speed is 100Mbps.

The above mentioned procedures do not effect to the parallel polling for the cell-to-cell move between micro-cells in a LMC. This is because those procedures to Pico-cell can be hidden behind the control of micro-cell. The control over Pico-cell is managed under the control over micro-cell since they are co-processed.

The radio resource in a micro-cell should be provided much enough to maintain the regularity of the polling for the packet transfer. For that purpose, enough number of packet channels should be provided in each Pico-cell. However, the increase of radio resources in Pico-cell is not large. This is because the Pico-cell configuration can be implemented without any interference between neighboring Pico-cells.

Addition of Pico-cell does not disturb the unified micro-cell concept. Use of radio channels in each Pico-cell is hidden from other micro-cells; therefore, packet transfer happens in the Pico-cell looks conducted in each micro-cell. Thus, continuous small double tier network allows efficient use of radio resources.

Another merit of provision of Pico-cell is saving of investment. The cell size of micro-cell can be increased if the Pico-cell provides large volume of radio resources. Then, the number of BSs can be decreased since small cell size of micro-cells is for the increase of radio resources by their
dense reuse in space domain

IV. A PICO-CELL IN EACH MICRO-CELL

According to the proposal for congestion relief with the small double-tier structure mentioned above, this section evaluates how the local congestion is liberated in term of mobile user throughput performance. Congestion concept is defined as a critical point at which the MT throughput achieved starts smaller than a given throughput. In our evaluation, the critical point is the maximum number of MTs in a cell.

Throughput of the mobile terminal is taken into consideration in two cases: before and after a Pico-cell is added in the micro-cell. Comparison of mobile user’s throughput from these two cases will indicate the performance of small double-tier structure in liberating the local congestion.

To prevent the temporal and spatial local congestion, Pico-cells are installed in each micro-cell without interference with each other. Packet transfer to and from MT is managed through the parallel polling if they are in the micro-cell area and the single polling mechanism is provided for MTs in the Pico-cell area. Therefore, calculation of MT’s throughput is carried out based on the analysis of polling procedures.

In the polling-based packet transfer, the throughput of a mobile user is defined by an interval of two consecutive polling signals that an MT received from base station. In the case of a normal polling, if a number of mobile terminals in one cell increases, throughput of an MT will decrease correspondingly due to the enlargement of the polling cycle. Not like the normal polling, the parallel polling imposes its copy on the two neighboring cells. Therefore, the fast-moving terminal with the assistance of parallel polling for quick handover between micro-cell has throughput affected by the number of MTs from two adjacent cells besides the MTs in its cell.

First, we calculate the throughput of the mobile terminal in micro-cell without Pico-cell. As reported early about the parallel polling in the section III, polling cycle of one MT depends on the time that polling ACK multicast in the terrestrial network (PON). Figure 8 shows the detail of the polling cycle estimation in the relation with ACK multicast and the packet transfer of other MTs.

We set $T_{poll\_cyc\_M} = n(T_{poll} + T_{ack} + 2SIFS + T_{data}) + (n-1)SIFS + 2n(T_{poll} + SIFS)$ (1)

If $T_{ACK\_PON} > T_{poll\_cyc\_M}$

MT throughput is given:

$$c_{MT\_M} = \frac{Data\_Size}{T_{poll} + SIFS + T_{ACK\_PON}}$$

If $T_{ACK\_PON} < T_{poll\_cyc\_M}$

MT throughput is:

$$c_{MT\_M} = \frac{Data\_Size}{T_{poll\_cyc\_M}}$$ (2)

Where: $T_{poll\_cyc\_M}$ is the polling cycle of an MT in the micro-cell; $n$ is the number of MT in the cell. $T_{poll}$, $T_{ack}$ and $T_{data}$ is the transmission time of polling, ACK and data respectively in the wireless section. $T_{ACK\_PON}$ is the time ACK of polling multicast in the terrestrial network (PON).

Second, we calculate the throughput of MT when a Pico-cell is added within the micro-cell. Throughput of MT is calculated as the average value of throughput that MT achieved because in this case MT can move either in micro- or Pico-cell.

Because the diameter of Pico-cell is half of micro-cell and the distribution of mobile terminal is uniform, so we assume that how many MTs exists in a micro-cell the same quantity also appears in the Pico-cell.

We set $T^{*}_{poll\_cyc\_M} = \frac{n}{2}(T_{poll} + T_{ack} + 2SIFS + T_{data})$ (4) is the polling cycle of an MT in the micro-cell with Pico-cell.

And $T^{*}_{poll\_cyc\_P} = \frac{n}{2l}(T_{poll} + T_{ack} + 2SIFS + T_{data}) + \frac{n}{2l}SIFS$ (5) is the polling cycle of an MT in the Pico-cell. $l$ is number of channels in a Pico-cell.

- If $T_{ACK\_PON} > T^{*}_{poll\_cyc\_M}$ and $T_{ACK\_PON} > T^{*}_{poll\_cyc\_P}$
Throughput is given by:

\[ C_{\text{MT}, M+P} = \left( \frac{\text{Data size}}{T_{\text{poll cyc}, M}} + \frac{\text{Data size}}{T_{\text{ACK PON}} p} \right) / 2 \] (6)

If \( T_{\text{ACK PON}} < T_{\text{poll cyc}, M} \) and \( T_{\text{ACK PON}} > T_{\text{poll cyc}, P} \)

In this case, throughput of MT which moving in both micro- and Pico-cell is influenced by the number of MTs.

Throughput of MT is express as below:

\[ C_{\text{MT}, M+P} = \left( \frac{\text{Data size}}{T_{\text{poll cyc}, M}} + \frac{\text{Data size}}{T_{\text{poll cyc}, P}} \right) / 2 \] (7)

All parameters used in our evaluation are borrowed from IEEE802.11a specification even though the wireless speed is 100Mbps. This borrowing can be accepted because the parallel polling mechanism in MM-MAN network is relied on the original polling procedure of IEEE 802.11 standard. In addition, the speed up of channel can be realized by increasing number of carriers used in parallel and degree of multiplexing, and thus, the gap time like SIFS (Short Inter Frame Space) will be maintained to eliminate the multi-path effect.

Figure 9 shows the change of throughput of MT before and after a Pico-cell is added in a micro-cell. Results are evaluated in different situations where the data packet sizes that MT transfers are not the same. The first point that can be easily recognized is that the larger data packet size is the higher throughput the MT achieves. This is because of polling overhead. The second point can be seen that MT’s throughput keeps constantly when the number of MTs is small. This can be explained that the ACK multicast time in the terrestrial network is longer than the total polling cycle of all mobile terminals at that moment. After that throughput start reducing when the number of MTs increases because from that time the packet transfers of other MTs dominate over the ACK multicast time.

When a Pico-cell is installed in a micro-cell, throughput that MT achieves is much higher than the case of only micro-cell. For example, in order to maintain the data rate at 2Mbps the number of MTs in a micro-cell should not be over 21. If a Pico-cell is added in a micro-cell, with the same data rate, the number of MTs in a micro-cell can increased to 50. This means the congestion is relieved when a Pico-cell is installed. If the number of channels in a Pico-cell changes to 2 or 3, the number of MTs that a micro-cell can support increases from 71 to 100. This concludes that with a Pico-cell added to a micro-cell, the offered traffic in the micro-cell will be shared between micro and Pico-cell so the congestion in the micro-cell is liberated.

V. CONCLUSION

This paper presented the local congestion situations of fast mobile users moving in unified micro-cellular network. They are the temporal and spatial congestion. To avoid these kinds of congestion, Pico-cell is installed in each micro-cell. The handover problems for the fast mover to and from the Pico-cell can be overcome by the normal polling through the central control of the BS of micro-cell. Installation of a Pico-cell in each micro-cell will reduce the congestion phenomenon in micro-cell. By the numerical analysis, we realize that the number of MTs served in the micro-cell increases 1.5 times if a Pico-cell is added.

REFERENCES