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Potential of the unified microcellular network in providing smooth high data rate connection to the fast vehicle moving in ITS

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Abstract This paper discusses the capability of the conventional double-tier and a unified micro-cellular network in supporting smooth handover for fast-moving terminals (FMTs). In the unified micro-cellular network, high speed packet transfer even to fast terminals is provided over the micro-cellular network along roads under the performance of parallel polling within LMC (Logical Macro-cell) consisting of several adjacent micro-cells. One of the advantages of the unified micro-cellular network is its potential in offering more resource than double-tier network. Its main disadvantage is inefficient resource caused by parallel polling. According to our evaluation in this paper, the unified micro-cellular network can support 3000 times more channel than double-tier system does. This can compensate inefficient resource use due to the parallel polling.

Keyword Double tier, unified micro cellular network, parallel polling, LMC, FMT

1. INTRODUCTION

Intelligent Transportation System (ITS) has been developed in the last few years with the aim of providing advanced information through the cellular networks to the road-transport. Services generated by the ITS can be automatic toll, services for guidance support, services for traffic control and service for driving safety. Together with the development of multimedia applications in the digital age, the expansion of these services in ITS to serve drivers and passengers becomes a real demand. One question needs to be answered is how network can catch frequent change between access points of fast mobile users in order to maintain the delay bound of real-time applications.

Double-tier hierarchical cellular network (Fig 1a) was presented as a candidate architecture to support for high-mobility as well as low-mobility. In this double-tier cellular network, FMT is served by macro-cell while micro-cell manages Slow-moving terminal (SMT). However, the main service assumed in such cellular network seems to be on voice band [1], [4]. High bit rate services is not mentioned clearly in these papers.

We have been developing a MM-MAN (Mobile Multimedia Metropolitan Area Network) as a 4G network component [2] (Fig2) in which not only normal mobile users but also fast-moving vehicles are able to exchange data through high-speed wireless link under the coverage of unified microcellular system. In order to deal with the high handover rate of FMT due to decrease of cell radius, parallel polling applied in MM-MAN will reserve the access permission in advance at the targeted cells within a dynamical LMC [3].

Considering the network capability allows high-bit rate packet transfer to fast terminals, this paper intends to compare the number of provided radio channels that unified micro-cells and the legacy of double-tier network can serve.

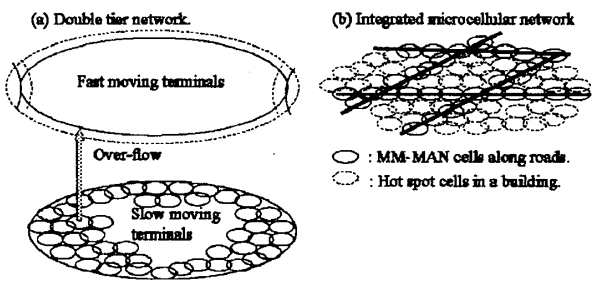

Figure 1- Double-tier and unified micro-cell network

2. DOUBLE-TIER AND UNIFIED MICRO-CELLS

2.1. Double-tier cellular network

Double-tiers cellular network shown in Fig.1 (a) has been considered to be a future network accommodating gigantic number of terminals including FMTs. Due to the frequent change of FMT between small coverage of micro-cells many researches [4] recommended the hierarchical

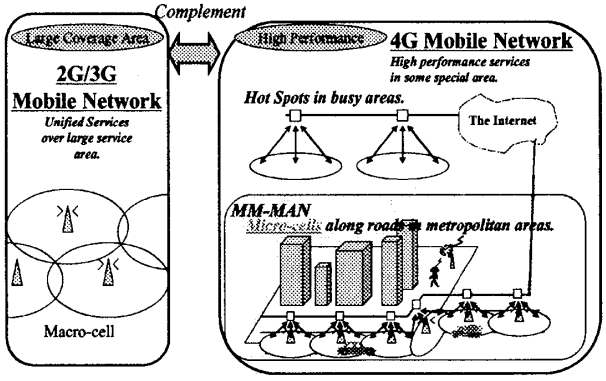

Figure 2 - Deployment of MM-MAN

architecture to overcome the high handover rate in micro-cell network. A typical hierarchical network is shown in Fig 1(a). One macro-cell is designed to overlay on a number of micro-cells. SMTs are assigned to micro-cells while FMTs are allocated to the serving of macro-cell with 5km of diameter. Because of large cell size of macro-cell, the existing time of FMT as well as the overlapping zone of adjacent cells become larger, handover rate of FMT is, therefore, considerably reduced. Besides, the macro cell can assist the portion of overflow traffic from micro-cell in case congestion happens. When one normal mobile user intends to connect to the cellular network, it will content the radio resource of the serving BS for registration and packet transfer. Meanwhile FMT served by macro-cell will be handled by polling for packet transfer if it needs a guarantee for QoS. However in such cellular network, two layers are separated physically that means capacity of macro-cell layer is very scare to adapt high data bit rate transfer [1], [4].

2.2. Unified micro-cells network

Not like the double-tier cellular network, in the unified micro-cells network, all types of mobile users are served under the coverage of micro-cells as shown in Fig 1b. For users need wireless connection inside the range of buildings or café, coverage of randomly installed hot-spots is sufficient for their demands. When mobile users plan to move on the street even with high-speed of transportation system and continue their high-speed Internet connection, the supplemental micro-cell system deployed along the road is necessary. A unified micro-cell based MM-MAN is such mobile network. To overcome the discontinuousness of connection for FMT due to fast handover between micro-cells, LMC and parallel polling is used. High-speed connection services can be met with the huge resources of micro-cells.

3. PACKET HANDLING TO FMT

One assumption is taken that the radio interfaces of double-tier and MM-MAN is designed for the shared radio channel. The considered issue here is how they satisfy the required radio channels to serve high-packet transfer rate for FMT.

3.1. Polling in Macro-cell of double tier

In order to satisfy high-speed services for FMT in the double tier cellular network, FMT has to access the radio resource of macro-cell by polling mechanism to transmit or receive data packets. It registers to macro-cell layer by contention to require polling grant for packet transfer. Each FMT will be polled to preserve the bandwidth for packet transfer; only small fix portion of the bandwidth is reserved for overflow traffic of SMT from micro-cell layer. Thus the number of channels in the macro-cell layer could be considered as a determined value, though

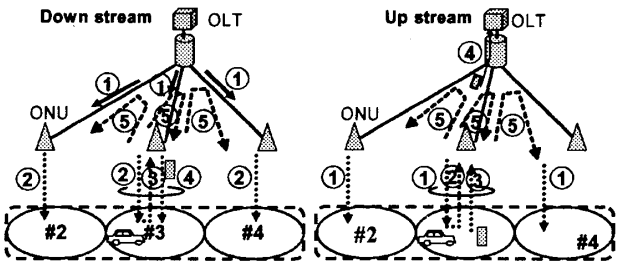

Figure 3 - Parallel polling in LMC of MM-MAN

another contention-based channel needs for registration. Normally, the portion of bandwidth reserved for registration purpose at the macro-layer can be set at the fix value due to the contention-based channel for data packet for any type of mobile users has been served at micro-cell layer. Packets transfer under the control of BS in macro-cell only depends on the schedule part of BS itself. In this cellular network, handover of FMT is done like soft-handover in the overlapped zone of the adjacent macro-cells.

3.2. Parallel polling in LMC of MM-MAN

In MM-MAN network, all the FMTs and SMTs share the channel of micro-cell for packet transfer. Registration processes of FMT as well as SMT occupy channel through contention-based access. In addition, contention–based channels are both used by SMTs for exchange packet with network and FMTs who do not need the guarantee of QoS. For FMTs intend to maintain their connection at the required grade of service, will be fulfilled through parallel polling mechanism that is operated within the dynamic LMC configuration. Packets transferred to FMT are multicast within LMC to prepare in advance at the target BSs. Polling signal is cast in parallel through the radio interface from all BSs in the LMC. When FMT gets into the new BS, it can rely on this polling to receive the buffered packets as well as send packets to network (Fig 3) [3]. Smooth handover of FMT is achievable between micro-cells owing to the parallel polling seen as symmetric polling in the virtual combined channels of LMC. However, handover frequency caused by FMT in MM-MAN is higher than that in double-tier where FMT is managed by macro-cells. Data rate of packet transfer depends not only on scheduler in the BS but

Table 1- Capability of double-tier and MM-MAN

Concerned issues	Integrated micro-cells	Double tier
Investments	Large	Large
Spectrum partitioning	Simple	Complicated
Handover frequency and packet loss in handover	Frequent, but no loss (Logical macro-cell and Parallel polling)[2]	Less frequent, and no loss (Channels are switched over with multiple radio interfaces)
Local traffic sensitiveness	Resources needed for the local maximum traffic	Averaged
Wasted radio resources	Polling to vacant cells	Latent channels to be used in micro-cells covered with a macro-cell.
Fast terminal support	Major roads	Whole area

also on the ACK multicast transmission time in terrestrial network to synchronize emission of parallel polling signals [3]. BSs in MM-MAN offer contention-based and polling-based channels. The number of channels in one micro-cell of MM-MAN, therefore, is allocated for FMT and SMT dynamically.

4. COMPARISON DISCUSSIONS

Typical features of both alternatives are shown in Tab.1. The fundamental background of the table is as follows;

(1) Investment: Both type of mobile network need a large amount of investment. Double-tier network requires extra BSs for macro-cell layer. While the number of BSs in the unified micro-cells network is installed a lot because the small coverage of each BS.

(2) Spectrum partitioning: Double-tier network involves complicated work to distribute frequency between two layers with the minimum interference and efficient re-use pattern as well. Unified micro-cells network only needs the optimization planning as a normal one-layer -cellular network.

(3) Handover frequency and packet loss in handover
Owing to parallel polling and LMC, packet loss during frequent handover of FMT in the unified micro-cells network is reduced. In the double-tiers network, it does not require fast handover for FMT so packet loss during handover is small rate.

(4) Local traffic sensitiveness: Traffic is fluctuated in the unified micro-cells network and averaged in double-tier network

(5) Use of radio resource

According to Table 1, radio resource of unified microcellular network is reported wastefully at the vacant cells. As discussed in [3], parallel polling is sent from set of BSs in LMC provided that MT exists in LMC range. This brings about the problem that polling signal is seen as a factor causing overhead at the cells where the MT is absent. Thus if one cell is taken into consideration, overhead is not only caused by polling emitted in the central cell itself, but also extra polling signals is compelled to emit from two adjacent cells in the case of three micro-cells LMC.

In order to estimate the wasted radio resources caused by parallel polling, we assume that if there is no FMT in the two neighbors then throughput of FMT in the central cell is largest and as a nominal value. The relative throughput is defined as how many percents throughput of FMT could achieve compared to the nominal value if the number of FMTs changes in two neighbors. ACK multicast transmission time in PON is set at $300\mu s$.

If the quantity of FMTs in the two neighbors is small like one, the relative throughput is kept at zero because the parallel polling produces at the central cell is not the main overhead factor rather than ACK multicast delay as shown in Fig4. When the number of FMTs raises more in the neighbors, the relative throughput starts reducing because at that time the parallel polling from neighbors dominate as the main factor causing overhead. Thus the number of FMTs in each cell should not be many to keep the packet transfer speed of FMT at the acceptable value. Moreover the size of LMC should be small enough from the viewpoint of saving radio resource when parallel polling is applied. Now we suggest the LMC size covers three micro-cells in MM-MAN.

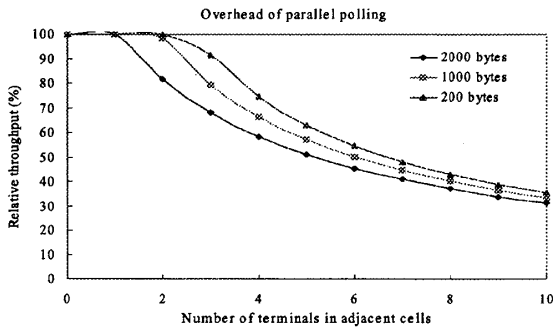

Figure 4 – Overhead of parallel polling

In the double-tier network, total capacity is shared between two layers, so the use of radio resource at the micro-cell layer will reduce the radio resource utilization at macro-cell layer

5. COMPARISON OF REQUIRED CHANNELS

In reality, the required radio resources of two systems should be considered but the detailed conditions of radio interface has not been much discussed yet. Hence within the range of this paper, we will evaluate how many channels can be gained when the unified micro-cellular network is adopted instead of the double-tier network. The coverage area of one macro-cell in double-tier network can be assumed exactly the same with that of total K_T micro-cells. With the same area of macro-cell, the coverage of MM-MAN along the roads is configured by K_M unified micro-cells.

The maximum throughput in the unified micro-cellular system is assumed to be that in the heaviest traffic cell. The traffic in each cell varies cell-by-cell, since the micro-cellular network is sensitive to the local traffic. The total traffic for the macro-cell system will be sum of the average value with coefficient ρ normalized from varying traffic pattern in micro-cell system (Fig5). Here, the capacity of the network is limited by that in the micro-cell with one polling-based channel given the heaviest traffic.

The reuse pattern m *(=3)* is assumed to be the same in macro-cell and micro-cell system, and it

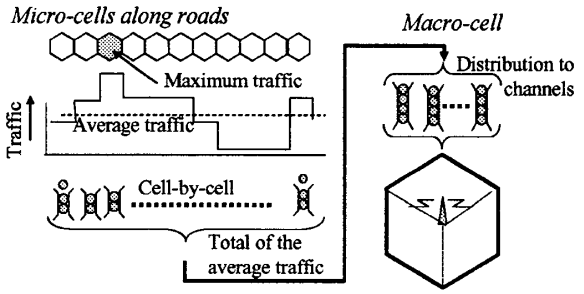

Figure 5 – Radio resource distribution in macro and micro-cell system

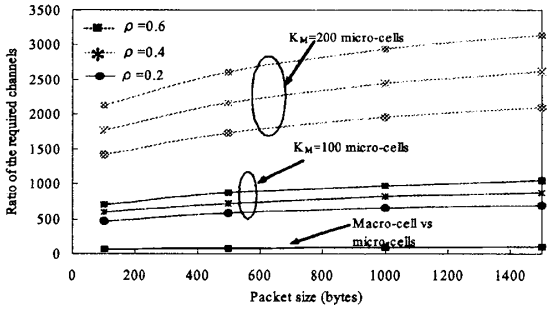

Figure 6 – Ratio of the required resource between double-tier and MM-MAN

should be put in the comparison evaluation because the resource utilization in macro-cell will disturb user's operation in micro-cell. For packet transfer in macro-cell layer, FMTs use polling-based channels, and catch one of them independently. It is fixedly used during each session. Thus the ratio of the required radio channels between macro-cell system and unified micro-cells system can be given as:

$$r = R_{c,M} + \frac{(K_T/ms)R_{P,M}}{R_{H,m}} = 1 + (K_T/ms)K_M \frac{(T_{poll}+T_{Data})\rho}{(T_{poll}+(n-1)T_{poll}+T_{Data})} \quad (1)$$

Where: T_{poll} and T_{Data} is transmission time of polling and data respectively, s $(=3)$ indicates the number of sectors in macro-cell. $R_{c,M}$ is number of channels for contention in macro cell. The number of polling channels in macro cell is $R_{p,M}$. In micro cell, the number of channels for parallel polling is indicated by $R_{H,m}$. Notice that in MM-MAN, parallel polling adds other poll signals from (n-1) neighbor cells in LMC to the central cell.

Figure 6 shows that the one macro-cell requires 130 times more channel than one micro-cell does. In our evaluation, T_{poll} $=20\mu s$ (OFDM in 802.11a), wireless rate is assumed 100Mbps and LMC consists of three micro-cells. In the calculation, packet size is assumed 1500 bytes, and the macro-cell needs to cover 200 micro-cells since the channels in macro-cell turns to the total number of channel of K_M unified micro-cells. Moreover if the whole coverage is considered, as of Fig6, macro-cell coverage includes 100 unified micro-cells, the channels given to macro-cell is about 3000 times higher than that required in micro-cells of MM-MAN in case of 1500 byte-long packet and ρ=0.6 because in MM-MAN those channels are distributed not only for one micro-cell but also for all K_M micro-cells. Therefore, MM-MAN can provide more channels and flexibility of channel usage to FMT in compare to double-tier network. MM-MAN is a proven choice to meet the diversified requirements of multimedia services towards 4G mobile network.

6. CONCLUSION

According to discussion in this paper, MM-MAN built on unified microcellular network can offer much higher wireless channels compared to the conventional double-tier cellular network. This proves capability of MM-MAN in providing high data rate connection to mobile users even to FMT through the assistance of parallel polling and LMC. ITS constructed by MM-MAN will fully satisfy all kinds of services to its mobile users.

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