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Macrocell Label Switching Mechanism for MPLS-WiMAX Networks

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Abstract. This paper proposes a fast *macrocell label switching mechanism* (MLSM) in the MPLS-WiMAX networks. The mobil station (MS) communicates with each other within macrocell, e.g., MS_A in the cell$_A$ communicates with MS_B in the other cell, and can be switched via the media access control (MAC) layer without involving the network layer. The average access delay of request from MSs is studied and analyzed in this paper. Finally, simulation results show that the purposed MLSM operates effectively and efficiently in terms of network throughput, average delay, and resource utilization.

Introduction

In the last decant, more and more users are interested in high-speed, high-capacity, and high-mobility over wider coverage areas and broadband access, termed third generation (3G) and beyond network, to support the different large-scale of data services [8]. To satisfy these requirements, it is important to design an all-label-switching-based transport infrastructure, which connects two or more the broadband wireless access (BWA) networks with the Internet [13]. The multi-protocol label switching (MPLS) is deployed in the Internet backbone to support service differentiation and traffic engineering [10]. In recent years, there has been interest in extending the MPLS capability to wireless access networks for mobility management support [9]. The IEEE 802.16d/e (denoted as 802.16) [6] wireless metropolitan area network (WMAN) standards, also termed WiMAX (worldwide interoperability for microwave access), provides a framework of BWA network based on various base stations (BSs). Such infrastructure can be three kinds of combinations: (a) the traditional 802.16 macrocell network (Traditional-802.16). (b) the MPLS-wireless network (MPLS-802.16), and (c) the macrocell MPLS -802.16 network (MLSM-802.16).

In the Traditional-802.16 network, two or more 802.16 networks are connected by the Internet-based backbone shown in Fig. 1 (a). The base stations (BSs) is used as a role of router/gateway [4] and processes packets from/to backbone to/from its (BS_A) or other cell's (BS_B) subscriber stations (SSs) or mobile stations (MSs). In this network all packets first look up in the network layer to compare IP and to find their destinations. Then, the packets can be relayed or forwarded. IP lookup, however, will cost a lot of overheads and greatly degrade the system performance when the transmitted data is heavy.

One of the efficiency ways to reduce IP lookup is MPLS mechanism [10]. The MPLS-802.16 network is the same as the Traditional-802.16 network, but the backbone is adopted MPLS-based backbone shown in the Fig. 1 (b). In this network, it uses the label switch path (LSP) technique [11] that provides high performance in packet delivery without routing table lookup. However, this network does not consider the BS is still using IP lookup transmission mechanism. Therefore, the performance of MPLS-802.16 network is limited in BS to do IP lookup twice, once in the BS_A and the other in the BS_B. These IP lookup also cost more overheads. The remaining challenge is to find a way let BSs avoiding IP lookup, then the MPLS-802.16 network may satisfy the desirous infrastructure.

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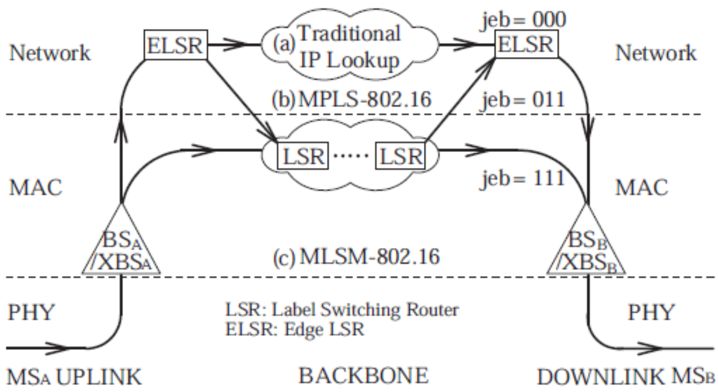

Fig. 1. The process of macrocell label switching mechanism.

To serve this problem, all packets can be efficiently switched in the MAC layer if a label switching mechanism is adopted in the BS. In this paper, we point out this problem and propose a macrocell label switching mechanism (MLSM) mechanism. The MLSM-802.16 network converges MPLS-based backbone and two or more enhanced edge label switching routers (ELSRs)-BSs (XBSs) as shown in Fig. 1 (c). This traffic can quickly go through the MAC layer if it can be identified by XBSA and XBSB. According to the label of MPLS [10], we adopt original MPLS-label for MLSM-based backbone traffic and local-label1[1] for local traffic. For backbone traffic, the XBS is used as a role of ELSR of MPLS in the MLSM-based backbone and can appliy/strip an MPLS label to the packets header. For local traffic, the XBS uses the reserved bits of the MAC header to identify whether the transported data is in the outgoing traffic for Internet or MLSM-802.16, or in the turnaround traffic. For the local label is packaged in the MPLS label, the traffic can be efficiently transferred as in the local area network (LAN) without interfering with the network layer, and thus, it enhances the macrocell system performance.

The remainder of this paper is organized as follows: Section II provides detail of MLSM mechanism. Section III describes the system model. Section IV describes the implementation of the proposed mechanism with simulation results. Finally, the conclusion and the future work are discussed in Section V.

MACROCELL MULTIPROTOCOL LABEL SWITCHING

The MLSM mechanism is considered macrocell differentiated service to user traffics of diverse requirements. It converges the original MPLS label for MPLS-based backbone traffic [11] and enhancing local label for local traffic. The local label uses three reserved bits of the generic MAC header called the j-bit, e-bit, and b-bit to notify the BS for layer 2 frame switching operations, where j-bit is used for outgoing or turnaround traffic indication, e-bit is used for Internet or MLSM-802.16 traffic indication, and b-bit is used for the request of cut-through switching forwarding or new entry establishment for this connection. First, if the traffic is outgoing, i.e., to the Internet or MLSM-802.16, the SSA will send these packets with a TCID and set the j-bit as 0. As the BS receives the burst data, it will be notified by the j-bit that these packets are outgoing and thereby deliver them to the higher layer, e.g., the convergence sublayer (CS), for unpacking or defragmentation operations and further IP lookup. Otherwise, this traffic is local and will be transferred by local label switching.
When the traffic is for the MLSM-802.16 and transfers at the first time, the jeb-bit shall be set as 010. It means that the burst data with the MPLS label and the TCID has not been set up yet in the label switching table. The BS, then, will forward the data to the network layer for IP lookup to create an MPLS label and coordinate with destination BS to create a TCID (source) to TCID (destination) mapping record in the label switching table for switching usage. Afterward, the MS can send data to the same destination with the MPLS label and the local label coded jeb-bit as 011. When the e-bit is set as one, it means that the MPLS label and the TCID mapping record have been built up. The

[1] The term 'local label' corresponds to the TCID in this paper.

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following data will be packet within an MPLS label to the packets header switched directly. The BSA will keep the MPLS label and this TCID as a reference for the destination MAC address. Similarly, the local traffic is transferred by the local label without the MPLS label. If the traffic is for the local and transfers at the first time, e.g., an SA transmits to MSC within the same cell, the jeb-bit shall be set as 110. The jeb-bit 111 is means that the TCID mapping record has been ready to switch directly in the local.

SYSTEM MODEL

The system is modeled as an MLSM-802.16 network. It is composed of two or more cells, each cell has an XBS, connecting by the MPLS-based backbone. This model is considered transfer delay in the BS. The MSs are connected to a centralized XBS over wireless fading channels, where multiple connections (data flows) are supported by XBS. Several assumptions are made as follows.

- The MPLS-based backbone is ready to support the MLSM-802.16 network in layer 2 label switching transmission.
- The call arrivals to/from an MS are a Poisson process with rate λ (the average number of MSs per frame.
- There are m servers, and each of them has an independently and identically distributed exponential service time distribution with mean $1/\mu$ (the average number of frames an SS requires from the resource).
- The length of each packet in the request of an MS is an exponential distribution with a mean length ℓ.

The measuring parameters are as follows.

ℓ The length of each packet in the request of an SS.

λ' The mean number of packets arrival rate of the IP lookup process.

μ' The mean service rate of the IP lookup process (the number of packets per frame).

T The expected steady-state system waiting time.

T_1' The IP lookup delay time in the XBSA in the sending BS, i.e., BS_A.

T_2' The IP lookup delay time in the XBSB in the receiving BS, i.e., BS_B.

T'' The processing delay in the MLSM.

$T_{M802.16}$ The IP lookup system processing delay of legacy MPLS-802.16.

T_{MLSM} The system processing delay time of MLSM.

The uplink resource allocation process of the IEEE 802.16 system can be treated as a multiserver $M/M/m$ model as shown in Fig. 2: Arrivals are Poisson with rate λ (the average number of MSs per frame). There are m servers, and each of them has an independently and identically distributed exponential service-time distribution with mean $1/\mu$ (the average number of frames an MS requires from the resource). Let C denote the capacity of the resource of uplink (the number of slots per frame). Based on the call admission control (CAC) rules, each MS is allowed to have the resource of mean k slots per frame for transmission if it is given permission to enter the system. The model satisfies the condition $C = mk$. We let $r = \lambda/\mu$ be the offered work load rate and $\rho = r/m = \lambda/m\mu$ be the offered work load rate to a server.

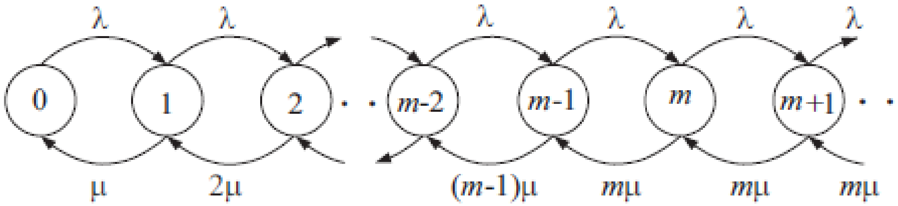

Fig. 2 The rate transition diagram for the $M/M/m$ queue.

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According to the $M/M/m$ model, we utilize the previous theory developed for birth-death processes [5] with steady-state probabilities to get the expected queue size L_q as

$$L_q = \left(\frac{\rho r^m}{m!(1-\rho)^2}\right) p_0, \tag{1}$$

where p_0 represents the probability of zero number of the PMS access the system and is equal to $1 = [r^m / m!(1-\rho) + \sum_{n-0}^{m-1} r^n / n!]$, where $\rho < 1$. To find the expected steady-state system waiting time T, we use the queueing delay T_q and the Little's formulas, $L = T$ and $L_q = T_q$, where L and L_q represent the number of MSs in the system and queues respectively, to get $T = 1/\mu + T_q = \mu + L_q / \lambda$ and we have

$$T = \frac{1}{\mu} + \frac{r^m}{m!(m\mu)(1-\rho)^2}\left(\frac{r^m}{m!(1-\rho)} + \sum_{n=0}^{m-1}\frac{r^n}{n!}\right)^{-1} \tag{2}$$

A. Delay of Legacy MLSM-802.16

The IP lookup processing server in the XBSA can be modeled as an $M/M/1$ model, since the output of an $M/M/m$ queue is identical to its input [3]. Assume the length of each packet in the request of an MS is an exponential distribution with a mean length ℓ. Let $h = k/\ell\mu$ be the number of packets in a request, then the mean number of packets arrival rate to the IP lookup will be $\lambda_1' = k\lambda / \ell\mu$. Let μ_1' denote the mean service rate of the IP lookup process (the number of packets per frame). We let $\rho_1' = \lambda_1' / \mu_1'$ be the IP lookup server queues, where ρ_1' is the traffic utilization. Then, T_1' can be obtained from

$$T_1' = \frac{L_1'}{\lambda_1'} = \frac{L\ell\mu}{k\lambda} = \frac{\ell\mu\rho_1'}{k\lambda(1-\rho')} = \frac{\ell\mu}{\ell\mu\mu_1' - k\lambda}, \tag{3}$$

where $L_1' = \rho_1' / (1-\rho_1')$.

Similarly, the IP lookup processing server in the XBSB can be modeled as (3). Assume that each MS is allowed to have the resource of mean k' slots per frame for transmission in the MPLS backbone. Let $h' = k'/\ell\mu$ be the number of packets in the MPLS backbone, then the mean number of packets arrival rate to the IP lookup will be $\lambda_2' = k'\lambda/\ell\mu$. Let μ_2' denote the mean service rate of the IP lookup process. We let ρ_2' is the traffic utilization. Then, T_2' can be obtained from

$$T_2' = \frac{L_2'}{\lambda_2'} = \frac{L\ell\mu}{k'\lambda} = \frac{\ell\mu\rho_2'}{k'\lambda(1-\rho_2')} = \frac{\ell\mu}{\ell\mu\mu_2' - k'\lambda}, \tag{4}$$

where $L_2' = \rho_2' / (1-\rho_2')$.

Combining (2), (3), and (4), we get $T_{M802.16}$ can be calculated by $T + T_1' + T_2' + T$ and assume that $k = k'$ and $\mu_1' = \mu_2'$. Then, $T_{M802.16}$ is equal to

$$T_{M802.16} = 2\frac{\ell\mu^2 + 2\ell\mu\mu' - 2k\lambda}{\ell\mu^2\mu' - k\lambda\mu} + \frac{2r^m}{m!(m\mu)(1-\rho)^2}\left(\frac{r^m}{m!(1-\rho)} + \sum_{n=0}^{m-1}\frac{r^n}{n!}\right)^{-1} \tag{5}$$

B. Delay of MLSM-802.16

The MLSM only needs to take one packet of a request (the same source-destination pair) every time for IP lookup since it will build up a label switching table in the MAC layer for fast cut-through usage. Notice that each request comprises several packets. The input traffic to the IP lookup process is the same as the average arrival rate λ to the MAC layer. Then, the traffic utilization of MLSM to IP lookup could be $\rho'' = \lambda / \mu'$. Therefore, the T'' can be obtained from

$$T'' = \frac{L''}{\lambda} = \frac{\rho''}{\lambda(1-\rho'')} = \frac{1}{\mu' - \lambda}, \tag{6}$$

where $L'' = \rho'' / (1-\rho'')$. The T_{MLSM} is equal to $T + T''$ and will be

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$$T_{\mathrm{MLSM}} = \frac{\mu+\mu'-\lambda}{\mu\mu'-\lambda\mu} + \frac{r^m}{m!(m\mu)(1-\rho)^2}\left(\frac{r^m}{m!(1-\rho)} + \sum_{n=0}^{m-1}\frac{r^n}{n!}\right)^{-1}. \quad (7)$$

NUMERICAL AND SIMULATION RESULTS

To compare the performance of MLSM with the legacy MPLS-802.16 mechanism, we adopt the QualNet 3.9.5 developer command-line simulator for practical IP lookup processing simulations [12]. The simulation is used to validate the numerical results obtained from TM802.16 (2) and TMLSM (7). The simulation environment is built up by one BS with a variable number of MSs sharing one 10 MHz bandwidth channel, which is operating in an orthogonal frequency division multiple access (OFDMA) PHY mode with a size of 1024 fast fourier transform (FFT) and the time division duplex (TDD) mode. Each OFDMA frame length is 5 ms long, the ratio of downlink to uplink is 2:1 , and the ratio of outgoing traffic to turnaround traffic F is 3:1. According to the standard, in the uplink, there are 35 subchannels in one channel and each of them has 24 data symbols. Each MAC-slot (in slot for short) is composed of three OFDMA symbols. Therefore, the capacity of the uplink C = 35 x 24/3 = 280 slots. The modulation and coding scheme is 16-QAM with 1/2 coding rate and each slot will carry 33.5 bytes.

The simulation results (the dotted lines) and the numerical results (the solid lines) are shown in Fig. 3. It shows that the simulation results match the numerical results in each case. The gap between the curves of simulation and analysis when ρ is low. For the reason, it is caused by the frame processing delay (one frame duration 5 ms) in the MAC layer of QualNet.

It can be observed that MLSM consistently outperforms the legacy MPLS-802.16 in access delay when ρ increases. Before saturation point, the increase is slow. Then delay starts to increase rapidly thereafter. This is because after reaching saturation status, the queue lengths in MSs, MLSM and the XBS all start to increase, given a fixed amount of available bandwidth at the XBS side. The M802.16 increases because of the delay caused by IP lookup (assume each packet needs 1 ms for IP looking up [1]). The IP lookup process in legacy MPLS-802.16 will be prolonged when ρ = 0.038, 0.076, 0.18 (ℓ = 3, 6, 9), because each packet has to process the IP lookup twice, once in the BSA the other in the BSB.

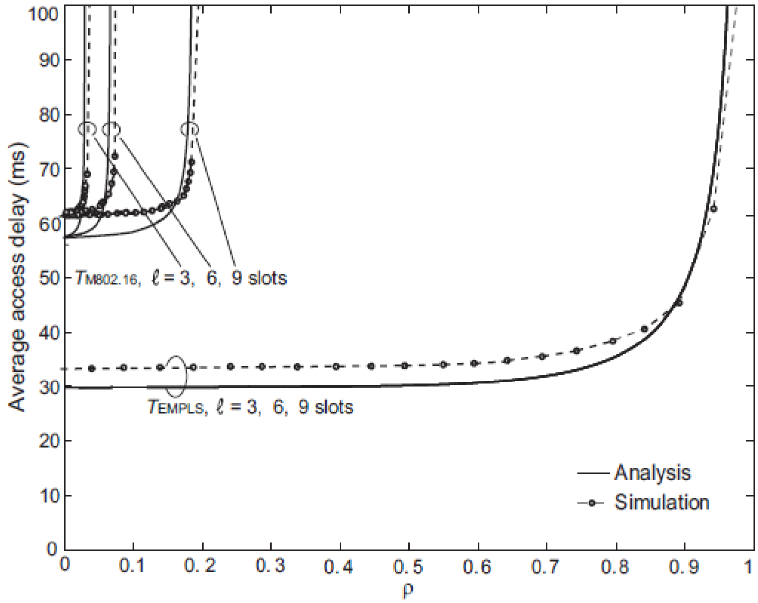

Fig. 3. Average access delay vs. ρ when $N_s = 132, \mu = 1/5.5, m = 11,$ and $k = 24$ under different $\ell = 3,6,9$ slots.

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Therefore, the more packets there are (smaller ℓ), the sooner $T_{M802.16}$ will reach infinity. On the other hand, MLSM will not be confined by the number of packets (different ℓ) because the streaming data will target to the same destination and IP lookup once and then it will be switched in the MAC layer. Obviously, $T_{M802.16}$ is twice as high as T_{MLSM} in each case. MLSM is suitable for the real computer networks since the statistical average packet size is only about 50–150 bytes ($\ell = 2$ to 4) long [7], while the legacy 802.16 suffers a longer delay for IP lookup.

It is an interesting observation on the access delay between $T_{M802.16}$ and T_{MLSM} as Ns increases in size. Fig. 4 illustrates the influence of different N_s = 66, 132, 264 per request on $T_{M802.16}$ and T_{MLSM} (264 slots/frame $\approx$ 14.2 Mbits/sec). From the results, both $T_{M802.16}$ and T_{MLSM} increase as ρ increases. It also shows that both $T_{M802.16}$ and T_{MLSM} increases when N_s increases. However, the T_{MLSM} has the half access delay of $T_{M802.16}$ in each case. The system capacity of legacy 802.16 will be saturated when ρ is approximately 0.34 and the average access delay will tend toward infinity. On the contrary, T_{MLSM} remains stable when $\rho \le 0.68$ and has longer delay when $\rho \approx 0.97$. This result indicates that MLSM can efficiently process most frequently used data streaming transmission activities in modern computer networks.

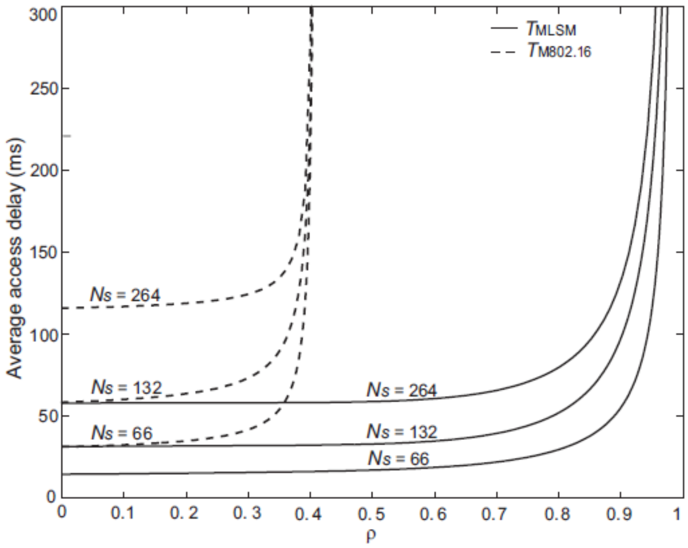

Fig. 4 . Average access delay vs. ρ when $k = 24, \ell = 18, m = 11$ and under different transmission lengths N_s = 66, 132, and 264 slots.

CONCLUSIONS

To solve the problem of the congestion and delay of data transmission, we propose an embedded MPLS mechanism named MLSM. This approach would boost throughput, reduce packet loss and delays, allow new capabilities like fairness controls and, what's better, it would save power, size, and cost. Simulation results show that MLSM outperforms the legacy IEEE 802.16 either in small or large packet sizes or even in huge multimedia streaming conditions.

ACKNOWLEDGMENT

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