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Cross-layer end-to-end label switching protocol for WiMAX–MPLS heterogeneous networks☆

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ABSTRACT

The integration of WiMAX networks and multi-protocol label switching (MPLS) networks, called WiMPLS networks, is the trend for nomadic Internet access in the fourth generation (4G) wireless networks. The base station (BS) in such heterogeneous networks will play the role of bridge and router between the IEEE 802.16 subscriber stations (SSs) and MPLS networks. However, there is no such integrated solution so far and the switching efficiency of the BS should be considered as well. This paper, therefore, adopts a cross-layer fashion (from network layer to MAC layer) to design the *end-to-end label switching protocol* (ELSP) for filling this gap. ELSP provides the mechanism of end-to-end (SS-to-SS) and layer 2 switching transfer for switching performance enhancement by assigning the SS with the MPLS labels (M-labels). The M-label can be carried by the IEEE 802.16e extended subheader within the MAC protocol data unit (MPDU), which is fully compliant with the IEEE 802.16e standard. The security issue caused by M-label usage is also concerned and solved in this paper. This paper also reveals an extra advantage that the switching delay of the BS achieved by ELSP can be as low as hardware-accelerated IP lookup mechanism, e.g., ternary content addressable memory (TCAM). Simulation results show that ELSP efficiently improves the end-to-end transfer delay as well as the throughput for WiMPLS heterogeneous networks.

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1. Introduction

The multi-protocol label switching (MPLS) technology is investigated for supporting service differentiation and traffic engineering in backbone networks (Le Faucheur, 1998; Nagarajan and Ekici, 2008). In recent years, there is a great demand for extending the capability of MPLS to wireless access networks for mobile access support (Langar et al., 2006, 2009). Meanwhile, an emerging broadband wireless access technology, the IEEE 802.16d/e standard (IEEE Working Group, 2004, 2006), is proposed for nomadic users in metropolitan area networks (MAN), also known as WiMAX (worldwide inter-operability for microwave access) networks. Nevertheless, the standard does not provide the mechanism of how to integrate WiMAX and MPLS networks.

In WiMAX networks, the base station (BS) plays the role of router/gateway to route packets from subscriber stations (SSs) to wired networks or vice versa (Chen et al., 2005). Consequently, the BS needs to play the role of bridge to convert packets from WiMAX networks to MPLS networks. Although Chen and Wang (2009) proposed a cross-layer cut-through switching mechanism (CCSM) for shortening the processing delay, this mechanism can only be applied in WiMAX local area networks (LANs) but cannot be extended to MPLS networks because MPLS uses the label switched path (LSP) label to route packets (Le Faucheur, 1998; Metz, 2001). Thus how to integrate WiMAX and MPLS networks (WiMPLS networks for short) efficiently, which motivates this work, is still an open issue (Dai and Chiang, 2007; Le Faucheur et al., 2002).

Several research works (Langar et al., 2006, 2009) focus on feasible frameworks to enhance the performance of the layer 2 transmission in the MPLS-wireless networks. Langar et al. (2006) present the mechanism of *micro mobile MPLS*, which integrates the mobile IP and MPLS protocols by using two-level hierarchy architecture. However, such a scheme cannot avoid IP lookup in the BS. Langar et al. (2009) show an *adaptive Master Residing Area* (MRA) which alleviates the limitations of previous works and benefits from MPLS resource provisioning capability, which can manage adaptively the mobile node according to its current state and the quality-of-service (QoS) constraints. Similarly, none of them contribute to the integration of WiMAX and MPLS networks.

In the IEEE 802.16e protocol (IEEE Working Group, 2004, 2006), the data packets from SS are packed or fragmented into one or several MAC protocol data units (MPDUs) before their transmission. It

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uses the transport connection identifier (TCID) number instead of IP address for MPDU transmission. The transferred MPDUs, which arrive in the BS, will be unpacked or defragmented into data packets for further IP lookup process. After the termination of IP lookup process of each data packet, the data packet will be fragmented or packed again into MPLS data units before entering the MPLS networks. The succession of packet conversion will lead to an inevitable delay in the WiMPLS networks.

The IEEE 802.16e standard provides an extended subheader (ES) function for carrying additional or extended information for particular operations. The motivation of this paper is that if the MPLS label (M-label) can be known by the SS, the SS can use the ES function to carry the M-label and then let the BS switch data frames in the MAC layer to MPLS backbone for *end-to-end transmission* in WiMPLS networks. In this way, the SS will share some loading of BS for routing packets and the BS only has to extract the M-label from the ES field and then forward it to the next M-label switching router (LSR) without much delay. To enable this, we began to investigate an SS initiated and cross layer enabled (from the network layer, L3, to the MAC layer, L2) end-to-end label switching protocol (ELSP) to let the BS have the capability for supporting the end-to-end packet transmission. Fig. 1 shows the general concept of the ELSP implementation as compared with the legacy way of WiMAX and MPLS integration. Notice that the BS plays the gateway of the first mile or the last mile when the both terminals are WiMAX users. In this way, packets can be fast transferred from one terminal to another terminal over these two types of networks. It is especially suitable for the multimedia streaming applications, e.g., the mobile voice over IP (VoIP) or mobile video conference, etc.

To evaluate the performance of ELSP, this paper gives a series of simulation and tests by comparing ELSP with two representative state-of-the-art IP lookup mechanisms, the software–hardware integrated solution called *fast IP lookup (FIPL)* (Taylor et al., 2003) and the hardware-depended special memory chip solution called *ternary content addressable memory (TCAM)* (Zheng et al., 2006). The results show ELSP can achieve as low switching delay as TCAM-enabled switch. This is another advantage of ELSP when integrating two types of networks. The main contribution of ELSP are highlighted below.

- ELSP provides a cross-layer, end-to-end (SS-to-SS) label-switching mechanism for packet forwarding in WiMPLS networks. The SSs can be either remote SSs or local SSs.
- The IP lookup will be taken only once by the BS when the SS does not have the M-label to its destination IP mapping notified by its serving BS (SBS). This advantage will be more significant especially in multimedia flows, which have the same source to destination pair.
- The packet forwarding delay is approximate to the IP lookup delay achieved by the hardware accelerated mechanism, e.g., TCAM. In other words, ELSP does not need expensive memory chips to achieve high performance.
- ELSP is fully compatible with the IEEE 802.16e protocol.
- ELSP provides the local SS-to-SS L2 switching mechanism within a BS's service area.

The remainder of this paper is organized as follows. Section 2 demonstrates details of ELSP mechanism and the intranet SS-to-SS switching mechanism. Section 3 presents the ELSP system model and corresponding delay and throughput estimation. The numerical analysis of the performance evaluation is given in Section 4. Section 5 presents the simulation results of the proposed mechanism. Finally, the conclusion and the future works are discussed in Section 6.

2. End-to-end label switching protocol (ELSP)

To enable the packet transmission through two different types of MAC configurations, which avoids the network IP lookup process, a MAC layer assisted switch routing has to be implemented in the intermediate node between these two configurations. The BS plays the role of intermediate node, which connects the wireless part and the wired part and, therefore, transfers the IEEE 802.16 data frames to the MPLS data frames. The IEEE 802.16e protocol provides a subheader extension scheme for further protocol extension usages.

First, on the side of the IEEE 802.16 protocol, the data frame is conveyed with the TCID as the identifier. Contrarily, on the side of the LSP, the data frame is conveyed and switched with the

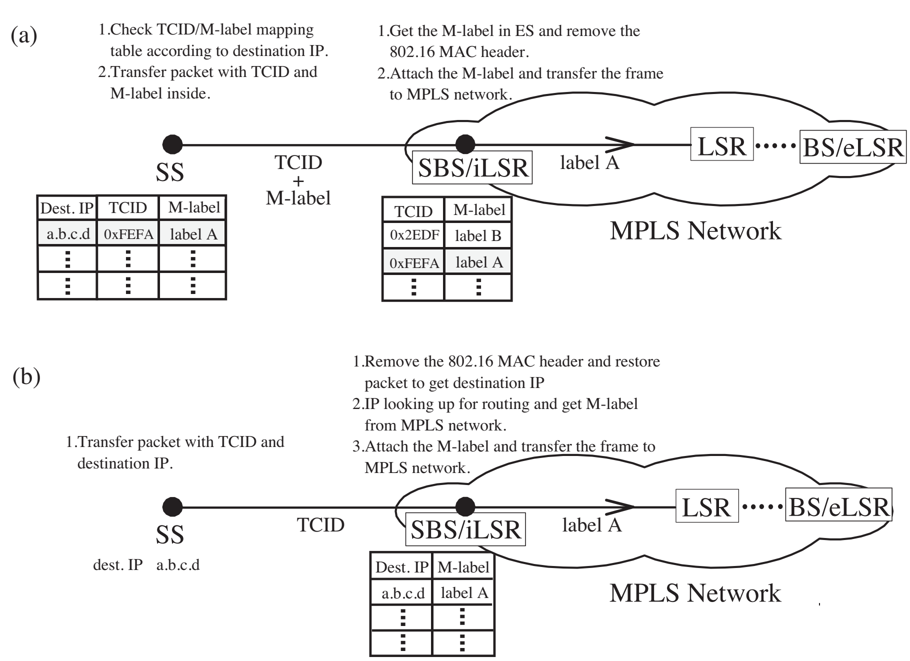

Fig. 1. The diagram of packet switching between ELSP and MPLS networks: (a) the ELSP mechanism and (b) the legacy way.

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