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RESEARCH ARTICLE

Mobility management in packet transport networks for network convergence

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ABSTRACT

Mobility management and quality of service (QoS) are two of the most important goals in the present and future development of wireless networks. These tasks involve not only the wireless domain but also the access network that interconnects mobile devices with the Internet. This emerging topic is known as fixed mobile convergence. The intention of this convergence is the integration and creation of a unified infrastructure from fixed and wireless mobile networks. In this converged infrastructure, users can move across networks and access services seamlessly. In this paper, we present a study on recent advances and open research issues on mobility protocols in conjunction with multi-protocol label switching (MPLS)-based access networks. Various mobile management protocols and their interaction with the access network are briefly introduced. A new architecture called integrated proxy mobile MPLS transport profile is also outlined to provide the highest integration level, QoS and high rates of mobility to achieve fixed mobile convergence. Copyright © 2013 John Wiley & Sons, Ltd.

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1. INTRODUCTION

In recent years, the growth of heterogeneous interconnected systems, and the appearance of new requirements in applications and services are progressively changing the original simplicity and transparency of the Internet architecture and the organisation of networks.

In the beginning of the Internet, the main goal was to interconnect stationary hosts. The emergence of smart phones and mobile devices has generated exponential growth in mobile data traffic. According to a recent forecast, global mobile data traffic has grown 70% in 2012, and this traffic will increase 13-fold between 2012 and 2017 [1]. Services like Internet Protocol (IP) television and video on demand will also be deployed in those networks and will impact on the actual network traffic [2]. This has made it necessary to adapt traditional protocols and access networks in order to accommodate this projected increase in mobile data traffic.

There are three important issues that must be resolved to accommodate mobile data traffic: the integration of heterogeneous networks, the network connectivity maintenance and the resource provisioning required by the mobile node (MN).

The first issue is addressed by fourth-generation (4G) wireless networks, which aims to integrate heterogeneous networks seamlessly in order to satisfy the increasing demand of the mobile users [3].

In this sense, traditional E1/T1 and Asynchronous Transfer Mode (ATM)-based access networks deployed in 2G and 3G are not viable because of the cost associated to adapt those technologies to new requirements such as quality of service (QoS), timing synchronisation, lower packet loss and high availability [4].

The seamless integration of heterogeneous networks in 4G is obtained by deploying all-IP architectures. To benefit from this deployment, various IP/multi-protocol label switching (MPLS)-based solutions were implemented in the access network [5–8].

Nowadays, many fixed network carriers have moved from IP/MPLS approaches towards MPLS transport profile (MPLS-TP) as the protocol to merge traditional fixed networks with packet-based transport networks [9]. MPLS-TP is based on the same forwarding mechanisms as MPLS but has enhanced operations, administration and maintenance (OAM) and protection capabilities, allowing it to become a true carrier class transport network technology and achieve higher rates of efficiency and lower operational cost, while maintaining transport characteristics [10].

Moreover, the integration of heterogeneous wireless networks is solved using IP-based mobility management protocols such as proxy mobile IPv6 (PMIPv6) [11]. This protocol tracks the movements of the MN and initialises the mobility signalling in order to set up the required routing state. This reduces the signalling of the MN and the complexity of the protocol stack. However, this approach presents some drawbacks, such as long handoff latency or large signalling load due to frequent registration updates.

The IP-based mobility management protocols solve the second issue, which is network connectivity maintenance, but resource provisioning is not resolved in a way that maintains the requirements of the MN.

To take advantage of the changes made by network carriers, improve convergence between the fixed and the mobile networks and resolve the increasing resource provisioning requirements of the MN, a new architecture called integrated proxy mobile MPLS-TP (IPM-TP) is proposed. This architecture increases the path protection mechanisms and supports dynamic topology changes and network optimisation produced by the movement of the MNs.

It also integrates the fixed and the mobile networks reducing the signalling overhead and latency in mobile communications and avoids packet loss when a handover occurs. Moreover, this architecture supports QoS management in wireless networks and introduces resiliency capabilities in the presence of high-mobility scenarios.

The remainder of this paper is organised as follows. Section 2 discusses the traditional mobility protocols and their integration with the access network. Section 3 introduces the proposed architecture designed for enhancing mobile device QoS by reducing latency and preventing data packet loss. In section 4, analytical models are presented to derive the handover latency, signalling cost, packet loss rate and the buffering size for all underlying protocols. The results are given in section 5. Finally, section 6 contains our concluding remarks.

2. MOBILITY MANAGEMENT PROTOCOLS AND THE ACCESS NETWORK

2.1. Proxy mobile IPv6

The PMIPv6 provides a network-based mobility support, which enhances manageability and flexibility by enabling network service providers to control network traffic. This protocol defines the basic infrastructure to track the MN movement using an IP-based protocol but does not implement any mechanism to provide QoS.

The PMIPv6 introduces two functional entities to the access network, the mobile access gateway (MAG) and the local mobility anchor (LMA). The MAG typically runs on the access router (AR). The main role of the MAG is to detect the movements of the MN and initiate mobility-related signalling with the LMA on behalf of the MN.

In addition, the MAG establishes a tunnel with the LMA for enabling the MN to use an address from its home net-

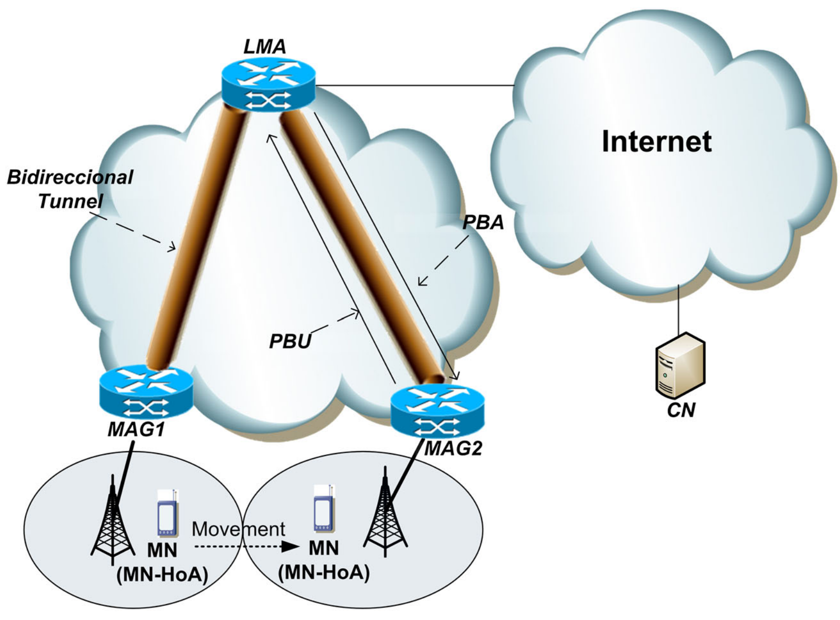

Figure 1. PMIPv6 domain. The MN changes the attachment point from MAG1 to MAG2 using the same MN home address (MN-HoA).

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work prefix and emulates the home network of the MN on the access network for each MN.

On the other hand, the LMA ensures that the MN address remains reachable while it moves, stores the information necessary to associate an MN with its serving MAG and enables the relationship between the MAG and the LMA to be maintained.

Figure 1 shows an MN performing its handover from MAG1 to MAG2 while its address, called MN home address, is maintained. The proxy binding update (PBU) and the proxy binding ACK (PBA) messages are sent to update the binding cache of the LMA and track the MN movement in the domain, using a new tunnel between the MAG2 and the LMA.

2.2. MPLS tunnel support for proxy mobile IPv6

The MPLS tunnel support for the PMIPv6 (PMIP-MPLS) [12] approach implements the same architecture as a PMIPv6 domain maintaining the MAGs and LMAs entities with the same functionalities.

The main difference between both protocols is the tunnelling mechanism used to deliver the packets from the LMA to the MAG. The Internet Engineering Task Force (IETF) advises the use of IP-in-IP or generic routing encapsulation (GRE) as tunnelling methods.

The IP-in-IP is a protocol by which an IP datagram may be encapsulated (carried as payload) within an IP datagram, by adding a second IP header to each encapsulated datagram. GRE is another tunnelling method that encapsulates any network layer packet. GRE requires an IP-in-IP header to encapsulate the information and also a GRE header to be added to the packet.

With the MPLS tunnel, the overhead added by the tunnelling method decreases because of the MPLS label size, which is 15 times less than the traditional IP-in-IP or GRE header needed by the tunnel (i.e. MPLS label size is 4 bytes in length, whereas the IP header size is 20 bytes in length).

Figure 2 depicts the MPLS tunnel support for PMIPv6 approach when a handover is produced.

If the MAG located at a previous access network (MAG1) detects the MN detachment, it sends a deregistration message to the LMA (messages 1 and 2). As soon as the de-registration message is received by the LMA, the Label Switched Path (LSP) tunnel is unsignalled.

When the MN attaches with the new MAG (MAG2) and sends a router solicitation (RS; messages 3 and 4), the MAG sends a PBU message to update the location of the

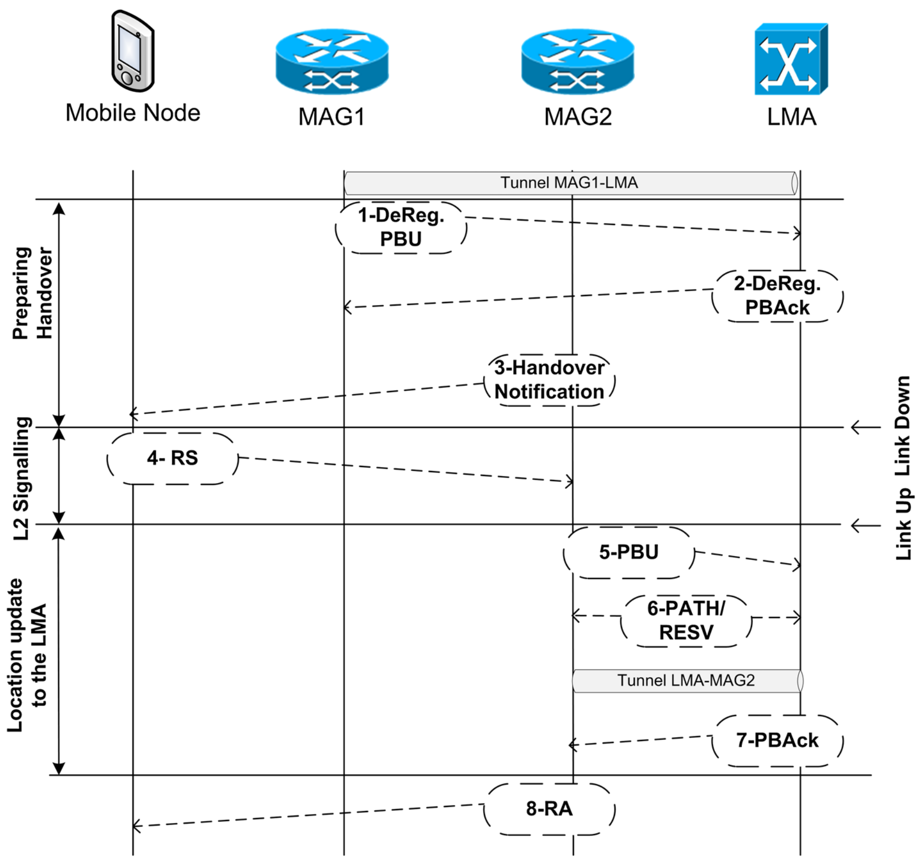

Figure 2. Handover process of the MPLS tunnel support for PMIPv6 approach. The MN detaches from MAG1 and attaches on MAG2. An LSP tunnel is created between the MAG2 and the LMA.

MN in the LMA (message 5). A new tunnel is created from the LMA to the new attachment point (MAG2).

The Reservation Protocol with Traffic Engineering (RSVP-TE) protocol is employed in the tunnel signalling phase sending PATH/RESV messages to signal the new LSP tunnel (message 6) [13]. The MAG is notified by means of a PBA message (message 7).

When the tunnel is created, a router advertisement message is sent. This message notifies that the attachment is completed (message 8).

In MPLS tunnel support for PMIPv6 when a handover is produced, a new LSP tunnel is created from LLMA to the different MAGs that serve the MN. During the handover, all in-flight packets are lost until the MN is attached to the new MAG.

3. INTEGRATED PROXY MOBILE MPLS-TP

In this section, the new approach called IPM-TP is presented. It integrates the heterogeneous wireless networks with the fixed packet transport network and supports dynamic topology changes and QoS provision to the network.

We assume that an MPLS-TP access network exists between the ingress label edge router/LMA (ingress LLMA) and the egress label edge router/mobility anchor gateway (egress LMAG). The ingress LLMA performs the role of an edge Label Edge Router (LER), filtering between intra-domain and inter-domain signalling. At the same time, this network element has the functionality of an LMA. The LMAG is connected to several access points that offer link-layer connectivity.

Here, we also distinguish between the link-layer functionalities of the air interface, which are handled by the access point, and IP-layer mobility (L3 handoff), which occurs when the MN moves between subnets served by different LMAGs. Note that an LMAG is the first IP-capable network element seen from the MN. Thus, the LMAG also performs the role of an egress LER. Figure 3 shows the behaviour of IPM-TP.

Messages 1 and 2 are produced when the MN detects the handover and notifies the serving gateway (LMAG1). The

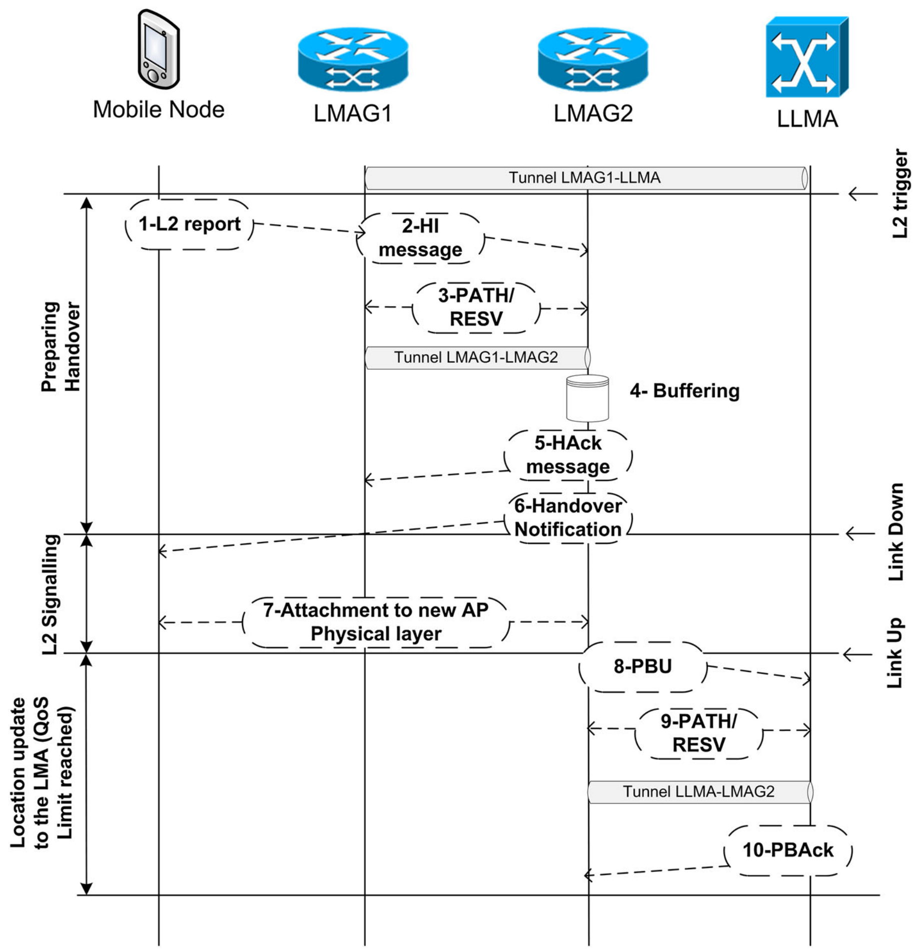

Figure 3. Handover process proposed in IPM-TP. The original tunnel from LMA to MAG1 is extended to MAG2 using a new segment of LSP.

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LMAG initialises the handover in the network sending a handover initiate message.

For messages 3–5, the LMAG1 tracks the mobility of the MN.

The LMAG1 chooses the best path and extends the LSP employing the usual MPLS-TP mechanism using the RSVP-TE protocol. The new LSP segment forwards all the packets sent to the MN, which will be attached in LMAG2. This LSP is created because the MN reports the ID of the LMAG to attach to.

Data packets are sent from the LLMA through the LLMA–LMAG1 tunnel and forwarded using the LMAG1–LMAG2 tunnel. The packets will be buffered in LMAG2 until the MN is attached. This buffering technique prevents packet loss. A handover ACK message is sent to the LMAG1 to notify it that the network is prepared to support the handover.

Messages 6 and 7 introduce the L2 signalling in the network. These messages notify the MN that the new wireless network, which it is going to attach to, is prepared.

Messages 8–10 handle the location update of the MN in the LLMA. When the QoS of a particular flow is under an agreed threshold assigned in the service level agreement or negotiated using RSVP resource reservation and is not satisfied, the LMAG updates the location with the LLMA. This is measured by means of the OAM capabilities included in MPLS-TP [9].

The LMAG sends a PBU message to update the binding cache of the LLMA. When this message is received, a new tunnel is created using RSVP PATH/RESV messages. Finally, a PBA message is sent to the LMAG2 to confirm the location update as described in PMIP RFC.

In the IPM-TP architecture, the original LSP tunnel is extended to forward all in-flight packets and buffer them in the new LMAG. This mechanism can be repeated while the QoS level can be satisfied. If it were not possible to continue extending the LSP, then the LMAG updates the new location of the MN in the LLMA with a standard registration procedure.

3.1. QoS provided by IPM-TP

As mention previously, the IP-based mobility management protocols standardised by the IETF do not provide any QoS to the communication. All packets are encapsulated using IP and are sent through the access network as best effort traffic.

The IPM-TP inherits the mechanisms to provide QoS to the communications because of the integration with MPLS-TP. The LLMA creates an LSP tunnel with different QoS parameters such as bandwidth, delay or jitter reservation. It also adds proactive identification of faults [14] and performance monitoring [15], which allows it to maintain optimal QoS parameters to the network communications.

The improvement in the handover latency searches for a trade-off between the packets that must be buffered in the access network to avoid packet loss and the delay penalisation introduced to the communication. If the handover latency is improved, the packet delay and the number of packets buffered will decrease. This implies that the QoS of the communication will be improved. IPM-TP architecture avoids QoS degradation by the aforementioned monitoring and identification of faults.

4. PERFORMANCE EVALUATION AND ANALYSIS

In this section, PMIPv6, MPLS support for PMIPv6 and IPM-TP approaches are compared through analytical models to derive the handoff latency, the signalling cost, the packet loss rate and the buffer size.

In this paper, the latency introduced by the handoff is defined as the time elapsed from the moment the handoff event is detected to the moment the first packet is received from the new subnet. In Table I, we present the notations used in our analysis.

4.1. One-way packet transportation delay on a wireless link

Wireless links are a vulnerable point in a network communication and one of the critical performance factors in communications between the MN and the fixed network.

Let p_f be the wireless link frame error rate and τ be the wireless link-layer inter-frame interval. Let $p_{i,j}$ be the probability that the first frame transmitted by the MN is received correctly by the AR, being i *th* retransmitted frame at the j *th* retransmission trial. The expressions for $p_{i,j}$ and the one-way frame transportation delay t_f between the MN and the AR with radio link protocol are given by [16]:

Table I. Notations used in the analysis.

Notation	Signification
T_{L2}	The link-layer handover latency, which depends on the L2 implementation.
T_{DRSol}	The random delay before sending the initial RS message.
T_{RSol}	The arrival delay of the RS message sent from the MN to the MAG in the new subnet.
T_{LU}	The delay of the location update from MN to the LMA.
T_{Pkt}	The delay to receive the first packet in the new subnet.
$S(\cdot)$	The size of a message. Messages can be PBU/PBA, RS, RSVP, data and tunnel encapsulation (TE).

RS, router solicitation; MN, mobile node; LMA, local mobility anchor; PBU, proxy binding update; PBA, proxy binding ACK.

$$p_{i,j} = p_f(1-p_f)^2[(2-p_f)p_f]^{\left(\frac{i2-i}{2}+j-1\right)} \quad (1)$$

$$t_f = D_{wl}(1-p_f) + \sum_{i=1}^{n}\sum_{j=1}^{i} p_{i,j}[2iD_{wl} + 2(j-1)\tau] \quad (2)$$

where $1 \leqslant i \leqslant n$ and $1 \leqslant j \leqslant i$, n is the maximum number of trials to transmit a frame over the link layer (typically, $n = 3$) and D_{wl} is the wireless link delay mainly depending on which L2 technology is being used.

Let $S(\cdot)$ and $S(frame)$ denote the length of a packet and the length of a wireless link-layer frame, respectively. Therefore, K is the number of frames per packet. It can be expressed as

$$K = \left\lceil \frac{S(\cdot)}{S(frame)} \right\rceil \quad (3)$$

The one-way packet transportation delay δ_{wl} between the MN and the AR is

$$\delta_{wl}[S(\cdot)] = t_f + (K-1)\tau \quad (4)$$

4.2. Handover latency of proxy mobile IPv6

Let $LH(PMIPv6)$ be the handover latency of the PMIPv6 protocol. Then, it can be expressed as

$$LH(PMIPv6) = T_{L2} + T_{DRSol} + T_{RSol} + \\ + T_{LU}(PMIPv6) + T_{Pkt}(PMIPv6) \quad (5)$$

where the T_{DRSol} can be determined as a value between 0 and $MAX\_RTR\_SOLICITATION\_DELAY$ [17]. Here, we assume that T_{DRSol} is uniformly distributed in the interval $[0, MAX\_RTR\_SOLICITATION\_DELAY]$. T_{RSol} is calculated as

$$T_{RSol} = \delta_{wl}[S(RS)] \quad (6)$$

where $S(RS)$ is the size of the RS message. We assume that the access network to the wireless domain has no message failure. Then, the $T_{LU}(PMIPv6)$ is denoted by

$$T_{LU}(PMIPv6) = nh\left(\frac{S(PBU)}{B_w} + L_w\right) + \\ + nh\left(\frac{S(PBA)}{B_w} + L_w\right) \quad (7)$$

where $S(PBU)$ and $S(PBA)$ are the sizes of the PBU and PBA messages, respectively, nh is the number of hops in the wired domain from the MAG to the LMA and B_w is the wired bandwidth of the link between the MAG and the LMA. Finally, L_w is the latency of the wired link (propagation delay). The delay to receive the first packet can be obtained as

$$T_{Pkt}(PMIPv6) = nh\left(\frac{S(TE_{IP}) + S(Data)}{B_w} + L_w\right) \\ + \delta_{wl}[S(Data)] \quad (8)$$

where $S(TE_{IP})$ and $S(Data)$ are the sizes of the IP-in-IP header and the data message, respectively. The IP-in-IP header is required by the tunnelling method implemented in PMIPv6.

4.3. Handover latency of MPLS tunnel support for proxy mobile IPv6

Figure 2 describes the handover process of PMIP-MPLS. Let $LH(PMIP-MPLS)$ be the handover latency of the MPLS tunnel support for PMIPv6 protocol. Then, it can be expressed as

$$LH(PMIP-MPLS) = T_{L2} + T_{DRSol} + T_{RSol} + \\ + T_{LU}(PMIP-MPLS) \\ + T_{Pkt}(PMIP-MPLS) \quad (9)$$

where $T_{LU}(PMIP-MPLS)$ is calculated by

$$T_{LU}(PMIP-MPLS) = nh\left(\frac{S(PBU)}{B_w} + L_w\right) + \\ + nh\left[\left(\frac{S(PATH)}{B_w} + L_w\right) + \left(\frac{S(RESV)}{B_w} + L_w\right)\right] + \\ + nh\left(\frac{S(PBA)}{B_w} + L_w\right) \quad (10)$$

where $S(PATH)$ and $S(RESV)$ are the sizes of $PATH$ and $RESV$ messages sent to signal the new LSP tunnel from LMA to MAG. Finally, T_{Pkt} is obtained as

$$T_{Pkt}(PMIP-MPLS) = \\ nh\left(\frac{S(TE_{mpls}) + S(Data)}{B_w} + L_w\right) + \delta_{wl}[S(Data)] \quad (11)$$

where $S(TE_{mpls})$ is the MPLS label size used in the LSP tunnel to transport the data messages from the LMA to the MAG.

4.4. Handover latency of integrated proxy mobile MPLS-TP

Figure 3 depicts the handover process using IPM-TP and the different phases that can be studied in the handoff. Let $LH(IPM-TP)$ be the handover latency of the proposed architecture. This can be expressed as

$$LH(IPM-TP) = T_{L2} + T_{Pkt}(IPM-TP) + Ts \quad (12)$$

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where Ts is the signalling method used by IPM-TP. Ts can be expressed as

$$Ts = \begin{cases} T_{LU}(IPM-TP) & X \approx QoS\_thr \\ 0 & X > QoS\_thr \end{cases}$$

where X is the QoS measured by MPLS-TP OAM functionality.

Ts will signal a link update when the QoS requirements are close to the threshold because of the excessive path extensions. The LMAG must notify the MN handoff to LLMA. Then, the LLMA must create the new path between the LLMA and the LMAG. Otherwise, Ts will extend the tunnel with a new segment in the path, and there are no extra signalling requirements. Then, T_{Pkt} is obtained as

$$T_{Pkt}(IPM-TP) = \delta_{wl}[S(Data)] \quad (13)$$

In Equation (13), the delay over the wired link is excluded. This delay has been taken into account in the PMIP and PMIP-MPLS approaches, Equations (8) and (11), but in IPM-TP, the packets are buffered in the new LMAG before the MN obtains the connectivity.

As mentioned previously, $Ts = T_{LU}(IPM-TP)$ is used when the QoS of the tunnels are near the QoS threshold. The LLMA must be notified using the regular PMIPv6 method. Then, $T_{LU}(IPM-TP)$ is calculated by

$$T_{LU}(IPM-TP) = nh\left(\frac{S(PBU)}{B_w} + L_w\right) + \\ + nh\left[\left(\frac{S(PATH)}{B_w} + L_w\right) + \left(\frac{S(RESV)}{B_w} + L_w\right)\right] + \\ + nh\left(\frac{S(PBA)}{B_w} + L_w\right) \quad (14)$$

where $S(PATH)$ and $S(RESV)$ are the messages sent to signal the new path between the LLMA and the LMAG2.

4.5. Signalling cost

Total signalling cost of registration updates during a session is denoted by Cu. The signalling cost is the accumulative traffic load on exchanging signalling messages during the communication session of the MN.

For each movement into a new subnet, the PBU message is sent to the LMA. This mechanism is performed in both PMIP and PMIP-MPLS. In IPM-TP, an LSP tunnel extension is created between the previous LMAG and the new LMAG to forward the packets to the MN. This LSP tunnel is extended while the QoS requirements are satisfied. The registration with the LLMA will be carried out when the threshold requirements are reached (i.e. the bandwidth or the delay is not satisfied). The expression of registration updates cost for all underlying protocols can be summarised as follows:

$$Cu(PMIPv6) = (S(PBU)nh + S(PBA)nh)N_{hv} \quad (15)$$

$$Cu(PMIP-MPLS) = (S(PBU)nh + \\ + S(PATH)nh + S(RESV)nh \\ + S(PBA)nh)N_{hv} \quad (16)$$

$$Cu(IPM-TP) = 2suN_{hv} + (S(PATH)nh_{LMAG} \\ + S(RESV)nh_{LMAG})N_{hv} \\ + (S(PBU)nh + \\ + S(PATH)nh + S(RESV)nh \\ + S(PBA)nh)N_f \quad (17)$$

where N_{hv} is the average number of level 3 handovers in a session, su is the average size of an L2 event signalling message, N_f is the average number of LSP tunnel extensions during a session and nh_{LMAG} is the number of hops in the wired domain from the previous LMAG to the new LMAG.

Then, N_{hv} is denoted as $\frac{t_s}{t_r}$ where t_s is the average connection time for a session and t_r is the average time at the visited network. N_f is denoted as $\frac{N_{hv}}{np}$, where np is the number of path extensions until the QoS requirements are close to the threshold.

4.6. Data packet loss

In this paper, we have presented different proposals that do not implement any buffering mechanism (i.e. PMIPv6 and PMIP-MPLS). With these protocols, in-flight data packets destined for an MN will be lost in the handover process. Suppose P_{loss} is the amount of data packet loss during the handover process. Let λ_s denote the average session arrival rate per second at the MN. P_{loss} can be derived as follows:

$$P_{loss} = \lambda_s E(S) LH(\cdot) \quad (18)$$

where $(\cdot)$ is one of the studied protocols (PMIPv6, PMIP-MPLS or IPM-TP) and $E(S)$ is the average session length in packets.

4.7. Buffering size

The buffer mechanism prevents the packet loss. The buffering size is required to evaluate the requirements of the buffer in network routers. In IPM-TP, the L2 trigger is used to anticipate the handover; therefore, we consider the L2 trigger time [18]. Suppose P_s is the probability of successful handover after the L2 trigger. It can be expressed as

$$P_s = \frac{1}{e^{kT\mu}} \quad (19)$$

where k is the scale factor and $T\mu$ is time taken from the occurrence of the L2 trigger. This value is related to the probability of a successful L3 handoff after a L2 trigger. A small $T\mu$ value implies a high probability of successful attachment.

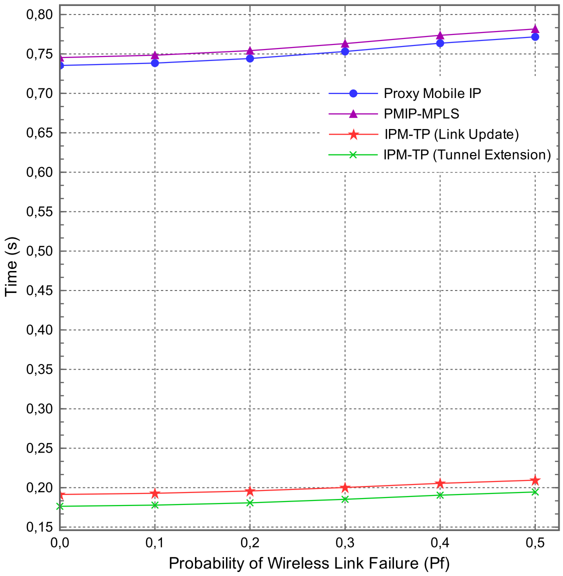

Figure 4. Handover latency versus wireless link-layer frame error rate.

In this paper, the buffering size *BuffSize* is the maximum buffer required to avoid the packet loss at the LMAG during the handover. This buffer is increased in proportion with λ_s and $E(S)$ and also increased in proportion with the handover latency inherent within the L2 technology.

$$BuffSize = P_s[\lambda_s E(S)(T_{RESV} + + T_{Handoff\_notification} + T_{Pkt})] \quad (20)$$

In this case, T_{RESV} and T_{Pkt} are assumed as having the same values as $T_{LU}(IPM-TP)$ and T_{RSol}, respectively. As the handoff notification is L2 dependent, a T_{RSol} is assumed as the maximum delay.

5. RESULTS

The following parameters are the basic configuration of the links delay and bandwidth of the network used in the analysis. These parameters are similar to those used in the paper [19]: $T_{L2} = 45.35$ ms, $B_w = 100$ Mbps, $L_w = 1$ ms, $D_{wl} = 10$ ms, $\tau = 20$ ms, *MAX_RTR_SOLICITATION_DELAY* = 1000 ms, $n = 3$, $nh = 5$, $nh_{LMAG} = 2$, $t_s = 1000$ s, $t_r = [5-50]$ s, $np = 5$ and $pf = [0.1, 0.5]$.

The sizes of the messages are defined as follows: $S(RS) = 52$ bytes, $S(PBU) = 76$ bytes, $S(PBA) = 76$ bytes, $S(TE_{mpls}) = 4$ bytes, $S(TE_{IP}) = 40$ bytes, $S(PATH) = 64$ bytes, $S(RESV) = 64$ bytes, $S(Data) = 120$ bytes, $S(frame) = 19$ bytes, $\lambda_s = 0.7$, $su = 50$ bytes and $E(S) = 14$.

Figure 4 shows the handover latency of PMIPv6, PMIP-MPLS and IPM-TP. As can be observed, the integration of the MPLS protocol in PMIP-MPLS produces similar handover latency even though the new LSP between LMA and MAG must be signalled. In fact, the mechanism reduces

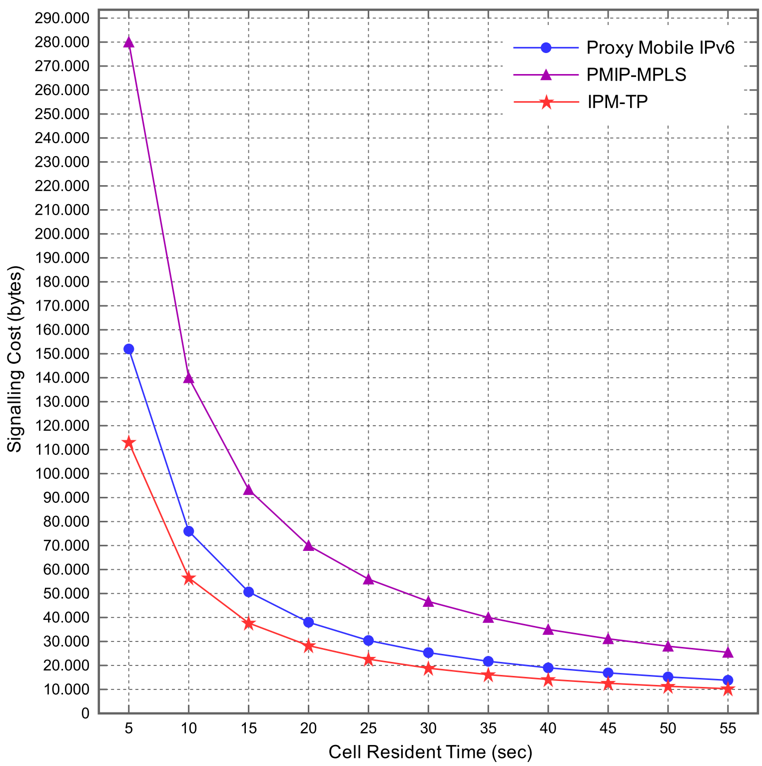

Figure 5. Signalling cost as a function of the resident time of the MN in a coverage area.

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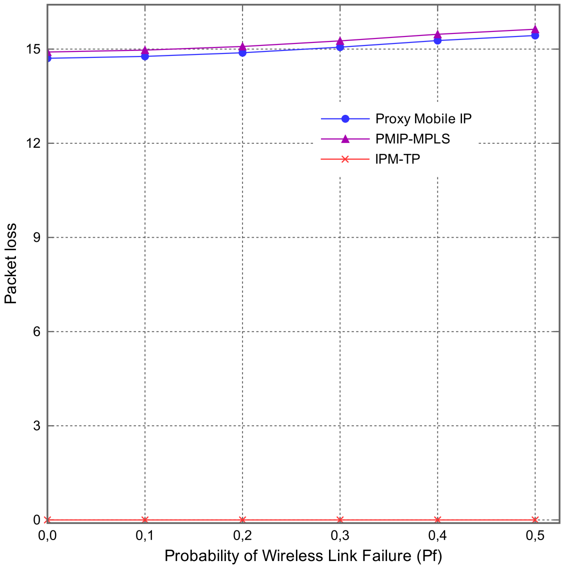

Figure 6. Amount of packet loss as a function of the probability of wireless link failure.

the overhead introduced in the network using an IP-in-IP tunnel as proposed by the standard.

The IPM-TP using tunnel extensions decreases the handover latency because the LLMA is not notified of the handoff and the LMAGs involved in the handoff resolve the movement of the MN.

This improvement decreases if the LLMA is notified of the handoff as can be observed in the IPM-TP with link update results.

We also observe that the IPM-TP architecture improves the handoff latency when the wireless link is unstable. This is because the proposed architecture relies upon only a few messages over the wireless link compared to the PMIPv6 and PMIP-MPLS protocol; that is, IPM-TP does not send any RS messages. These messages are sent in an interval of between 0 and 1 s.

In IPM-TP, this message is supplied by the L2 trigger, which detects that the wireless link is going down, and the MN notifies the LMAG that the MN is going to abandon the coverage area. The MN also notifies the new LMAG it is going to connect to.

This can be taken advantage of by the access network to extend the tunnel from the previous LMAG to the new LMAG and decrease the handover latency as Figure 4 showed. This mechanism improves the QoS when the mobility of the MN is high.

Figure 5 shows the signalling cost of the underlying protocols. As can be observed, PMIP and PMIP-MPLS have a high registration cost because of the frequent registration with the LMA to update the binding cache. Any movement carried out by the MN must be registered with the LMA, and this increases the overhead in the network.

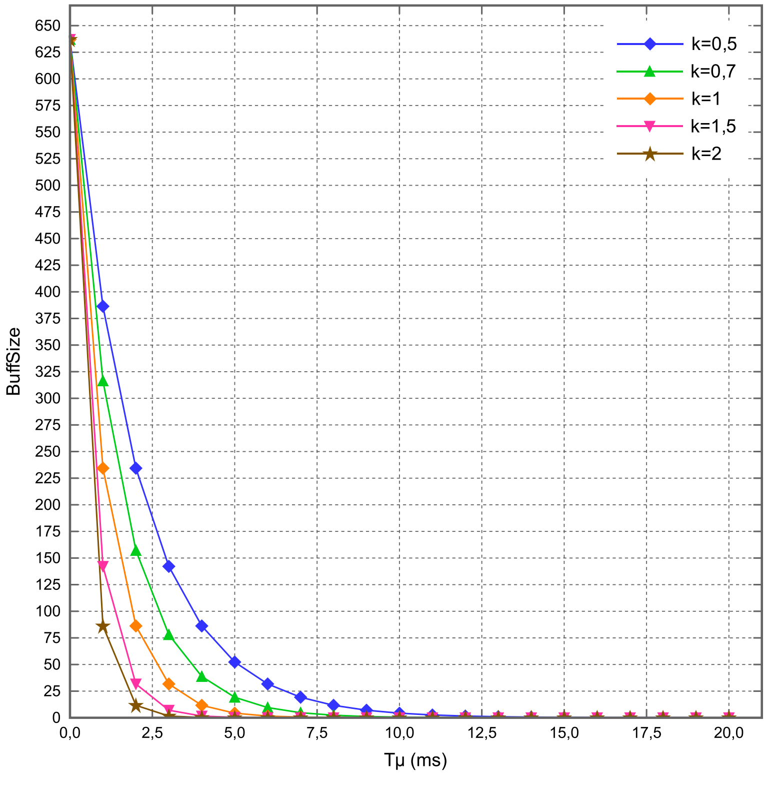

Figure 7. Buffer size as a function of the occurrence of the L2 trigger.

PMIP-MPLS has the higher registration cost because the LSP tunnel is signalised, and this increases the signalling cost. With the IPM-TP approach, the registration overhead is reduced by around 25% compared with PMIPv6 and 59% compared with PMIP-MPLS.

Figure 6 shows the packet loss against the wireless link-layer frame error rate. Assuming the wireless link-layer frame error rate varies from 0 to 0.5.

The packet loss increases as the wireless link-layer frame error rate increases. This is produced because the packet loss during a handoff is proportional to the handoff latency in the model.

The IPM-TP approach avoids the packet loss because the L2 trigger signals the movement and can reroute the packet in the access network to the new LMAG, which is going to serve the MN.

This LMAG will also implement a buffering technique to store the in-flight packets. When the MN is attached to the new LMAG, all the packets will be delivered to the MN. As can be observed in Figure 6, packet loss is avoided with this technique.

Figure 7 shows the buffering size incurred in the proposed handover process. In the analysis, $T\mu$ is varied from 0 to 14 ms.

As mentioned in the previous section, $T\mu$ is defined as the time taken from the occurrence of the L2 trigger event to start the real L2 handoff. This implies that a small value of $T\mu$ was close to a real handoff and implies a high packet loss probability.

As can be observed, the *BuffSize* decreases as $T\mu$ increases because the handover anticipation is completed before the MN loses connectivity.

The buffer size requires that a trade-off be found between the L2 trigger and the packet buffered that decreases the handover latency in order to reduce the resources used by each MN that simultaneously moves to the LMAG.

As can be observed in Figure 7, when $T\mu = 0$ ms, all in-flight packets sent to the MN must be buffered during the handover until the MN is attached to the new LMAG.

The number of packet buffered is directly related to the handover latency.

The optimal L2 trigger is in $T\mu = 12$ ms. This value is the best L2 trigger to avoid packet loss and improve the connectivity of the MN when a handover is produced.

6. CONCLUSIONS

This article presents a novel architecture called IPM-TP, which supports seamless mobility management, traffic engineering and QoS and encourages network convergence.

The architecture presented is a simple and cost-effective packet-based access network solution, which merges traditional fixed and mobile networks, and enables the integration of wired networks and 4G mobile broadband access technologies into future fixed mobile convergence, which is one of the providers' main open issues.

With IPM-TP, the QoS offered by the network to the MNs is improved through the reduction in handoff signalling messages, which also reduces the handoff latency and the signalling cost. Therefore, packet loss is avoided. To demonstrate this, a comparison between the proposed IPM-TP architecture and the existing solutions (PMIP and PMIP-MPLS solutions) was made.

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