A Scalable Fast Handovers Proxy Mobile IPv6 Scheme for 4G Wireless Networks

Lebajoa A. Mphatsi

National University of Lesotho, Department of Mathematics & Computer Science,

Summary
Proxy Mobile IPv6 (PMIPv6) is one of the most promising mobility solutions for the next generation wireless networks. PMIPv6 has been recommended for the Third generation partnership project's (3GPP) Evolved Packet Core (EPC) and has been adopted by the WiMAX forum. However, PMIPv6 in its current state does not attain the stringent handover performance required to support high quality of service (QoS) for real time services. To improve PMIPv6's handover performance, bicasting schemes for PMIPv6 have been proposed in the literature to minimize packet loss and handover delay during a PMIPv6 handover. However, existing bicasting schemes for PMIPv6 require a significant amount of backhaul bandwidth as well as buffer space to attain a seamless handover. Therefore, this paper studies bicasting schemes for PMIPv6 and consequently proposes an enhanced bicasting scheme for PMIPv6 that not only reduces the handover delay and packet loss but also efficiently utilizes the scarce and shared network resources to ensure scalability. The proposed solution uses the signal strength behavior to make decisions on when to start and stop bicasting. A model of the proposed solution is implemented and incorporated into the Network simulator-2 (NS-2). The results obtained indeed show that the proposed solution surpasses currently existing solutions.
Key words:
mobility, bicasting, network resources, efficiency, timing

1. Introduction

The next generation wireless networks promise ubiquitous services for mobile users roaming different radio access technologies that make use of an IP-based core network [1]. Therefore, it is paramount for handovers to be seamless in the next generation wireless networks to maintain an acceptable QoS for mobile users. It is due to this that mobility management research groups are continually proposing and implementing extensions to the currently existing mobility management schemes as an endeavor to improve the handover performance. Mobile users should not experience a perceivable disruption in the offered service as the point of attachment changes. However, many well accepted current solutions (e.g. Mobile IPv6 [2], Proxy Mobile IPv6 [3]) are still not able to offer a non-perceivable interruption when a mobile user undergoes a handover [4]. This is primarily caused by the duration when the mobile node (MN) is unable to either transmit packets to the network or receive packets from the network which is referred to as the handover delay. Handover delay can cause packet loss, resulting in a disruption on an ongoing communication.

In an endeavor to improve PMIPv6's handover performance, bicasting schemes for PMIPv6 have also been proposed in the literature to reduce packet loss and handover delay during a PMIPv6 handover. With these solutions, packets are duplicated and sent to both the current MAG (PMAG) and the candidate MAG (NMAG) during the handover. Thus, packets that were lost on the then previous MAG (PMAG) because the MN was then out of coverage can be buffered on the candidate/next MAG (NMAG) and be forwarded as soon as the MN successfully attaches to NMAG. Therefore, the packet delivery ratio is increased. Bicasting solutions also employ the technique of proactive handovers, thereby allowing a number of handover procedures to be carried out in advance to lower the handover delay. This is achieved by employing cross-layer techniques whereby the link-layer information is used to predict the handover occurrence.

Current packet-loss minimization techniques and solutions for Proxy Mobile IPv6 that are based on bicasting of IP packets during a handover result into wastage of network resources. This is due to the fact that packets are duplicated and hence the need for utilization of more network resources and an increased network load. This translates to an increased bandwidth requirement. On the other hand, buffering requirements are highly needed for these solutions to work. But, since the buffer space is not infinite, these solutions may not scale to the increase of mobile data traffic that is anticipated in the future.

The above arguments are supported by the Motorola LTE Technical Review White paper [5]. It is argued that a bicasting solution requires significantly higher backhaul bandwidth, and may still not be able to avoid data loss altogether. Moreover, determining when to start bicasting is an important issue to address in the bicasting solution. If bicasting starts too early, there will be a significant increase in the backhaul bandwidth requirement. If bicasting starts too late, it will result in packet loss. There will also be a high bandwidth requirement if bicasting delays to stop or stops too late. On the other hand, if it stops prematurely/too early, it will result to higher packet losses [5].

Manuscript received June 5, 2016
Manuscript revised June 20, 2016

The rest of the paper is organized as follows: Section 2 reviews bicasting schemes for PMIPv6 in the literature. Section 3 gives an in-depth discussion of the proposed bicasting solution that promotes efficient resources utilization. In section 4, the simulation setup that was used to test models of the PMIPv6 and bicasting schemes for PMIPv6 is discussed. Performance results and their analyses are discussed in section 5. Lastly, the paper is concluded in section 6.

2. Related Work - Bicasting Schemes for PMIPv6

2.1. Bicasting PMIPv6 (B-PMIPv6)

Ji-In et al in [9, 10] proposed a bicasting based PMIPv6 (B-PMIPv6) scheme to lower handover delay and packets loss so as to evade packet arrival fluctuations caused by a handover. Firstly, B-PMIPv6 employs the use of predictive handovers so as to lower the handover delay whereby the route to the next point of attachment is set up in advance when a handover is imminent. Secondly, B-PMIPv6 increases the possibility of receiving all packets send by the corresponding node by duplicating packets to the current and candidate (subsequent) points of attachment (MAGs) when the signal strength degrades to a certain set threshold namely the LINK_GOING_DOWN (LGD) power level/threshold. Even though this solution also proves to minimize handover delay and packet losses, it utilizes a significant amount of network resources (backhaul bandwidth and buffer space) since it delays to stop bicasting.

2.2. Simultaneous bindings PMIPv6 (SPMIPv6)

Bargh S.M. et al also proposed PMIPv6 with simultaneous bindings (SPMIPv6) [11] to reduce the handover latency for the next generation wireless networks. The solution uses multiple triggers as proposed by Guan W. et al in [12] to facilitate anticipation of a handover. Through the adoption of a proactive handover, the solution is able to perform other handover operations before the handover occurs and hence lower the handover delay. Packet bicasting occurs during the handover and is controlled by PMAG (Handover coordinator). In this solution, when a handover is imminent, PMAG instructs NMAG to send a PBU with a bicasting option set. Thus, similar to B-PMIPv6, SPMIPv6 starts bicasting when a handover is imminent.

2.3. Partial bicasting for PMIPv6 (PB-PMIPv6)

Ji-In et al in [13] further improved B-PMIPv6 and proposed a partially bicasting PMIPv6 (PB-PMIPv6) whose aim was to solve the problem of inefficient backhaul bandwidth utilization by bicasting packets to PMAG and NMAG for a very short time. Similar to B-PMIPv6, PB-PMIPv6 also employs the use of predictive handovers to lower the handover delay incurred when a MN changes points of attachment within a PMIPv6 domain

3. Proposed enhanced bicasting for PMIPv6 (EB-PMIPV6)

3.1 Design Goals

3.1.1. Seamless handover support

It is paramount for EB-PMIPv6 to improve the handover performance of PMIPv6. Therefore, EB-PMIPv6 seeks to lower packets loss, and the handover delay that causes packet arrival fluctuations at the MN. The mobile user consuming real-time delay sensitive multimedia services should not perceive degradation in the QoS as handovers are performed. EB-PMIPv6 attains this by anticipating the handover and thus performs some handover operations ahead of time so as to eliminate their latencies from the total delay incurred for the MN to continue its communication after the transient disruption caused by a handover.

3.1.2 Network Resources Utilization Efficiency

Since bicasting solutions are criticized for their significant requirement of network resources to provide soft handovers, EB-PMIPv6 seeks to address this demerit. The proposed EB-PMIPv6 routes (bicasts) packets to the current and subsequent points of attachments for a short duration. This is performed to minimize the time taken utilizing double the amount of backhaul bandwidth that is utilized under normal circumstances (when there is no handover).

3.1.3 Robustness with respect to handover predictions errors

The proposed solution relies on predictive link-layer triggers to prepare for execution of handover operations as well as bicasting. Since predictions could raise false alarms, EB-PMIPv6 should be able to recover from the errors (e.g. false alarms) with (1) no effect on the QoS experienced by the mobile user and (2) no substantial waste of network resources.

3.2 EB-PMIPv6 Design

3.2.1 EB-PMIPv6 – MAG Modifications

EB-PMIPv6 on the MAG side provides a coordinated service for link-layer trigger generation to assist in handover preparation (for proactive handovers) as well as timely and accurate execution of bicasting operations. Link-layer triggers can be generated based on a range of link layer quality factors such as the received signal strength, data rate, packet errors, etc. In this proposed solution, the received signal strength (RSS) is used to reflect the link-layer quality because the signal strength is one of the main determining factors for successful reception of packets at the MN. The link-layer triggers employed in the proposed solution are triggered at the signal strength (power) boundaries/thresholds identified in the document by the National Institute of Standards and Technology (NIST) Seamless and Secure [14].

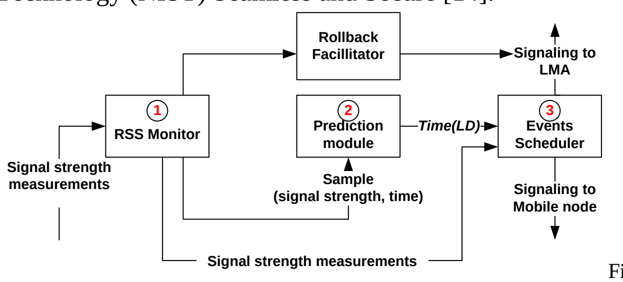

Fig. 1 EB-PMIPv6 design on the MAG side

3.2.1.1. Received signal strength monitor (RSS monitor)

The primary function of the RSS Monitor is to monitor the MN's signal strength as the MN roams the wireless networks. Besides the thresholds adopted from B-PMIPv6, EB-PMIPv6 defines two other triggers *T1* and *T2* at two signal strength (power) levels P_{T1} and P_{T2} respectively that are equally spaced from P_{LGD} by a small offset Δ_P as stated in equations (1) and (2).

$$P_{T1} = P_{LGD} + \Delta_P \qquad (1)$$

$$P_{T2} = P_{LGD} - \Delta_P \qquad (2)$$

The RSS monitor starts monitoring the signal strength once it decays to threshold P_{T1}. During RSS monitoring, the RSS Monitor, records the power level of the packet received and the corresponding time as the signal decays to P_{T1} , P_{LGD} and P_{T2} . The RSS Monitor is also responsible for alerting the Rollback facilitator module if the signal strength then increases instead of decreasing as previously predicted. Once the signal strength deteriorates to P_{T2}, the recorded tuples *(power level, time)* collected are passed to the prediction module.

3.2.1.2. Prediction module

The Prediction module uses the samples passed by the RSS Monitor to predict the viability of the decaying link through the pattern shown by the samples from the monitor. The prediction module estimates the amount of time left before the link actually breaks which is called link viability in the report. Knowing the link viability, the proposed scheme can then timely and accurately execute the *start bicasting* and *stop bicasting* events as close as possible to the LINK_DOWN event. The viability is also used to determine when to trigger a redirection of the flow of packets at the LMA from PMAG to NMAG. The output of the prediction module is the time at which the Link down (LD) event is estimated to be, which is when the MN will no longer successfully receive packets from the PMAG (below signal strength *RXThresh_* (P_{LD})).

Thus, for proof of concept purposes, the proposed EB-PMIPv6 solution adopts a link breakage prediction algorithm used for a dynamic source routing (DSR) protocol in [15] to increase packet delivery ratio. In this prediction algorithm, the Two-ray ground radio wave propagation model is utilized in modeling the signal strength decay behavior in the wireless network. In the literature, there is a wide range of prediction algorithms and tools that have been used in signal strength predictions. Some of them are the least mean square adaptive filters and Fast Fourier Transform-based signal analysis algorithms. However, to focus on the timely execution of bicasting operations problem mentioned earlier, this work utilizes a prediction algorithm used in [15] that employs the two ray ground propagation model.

In order to discuss the prediction algorithm, this research considers a scenario whereby a MN moves away from an access point (AP) or base station (BS) which is collocated with the MAG as shown in Fig. 2 in a uniform linear motion.

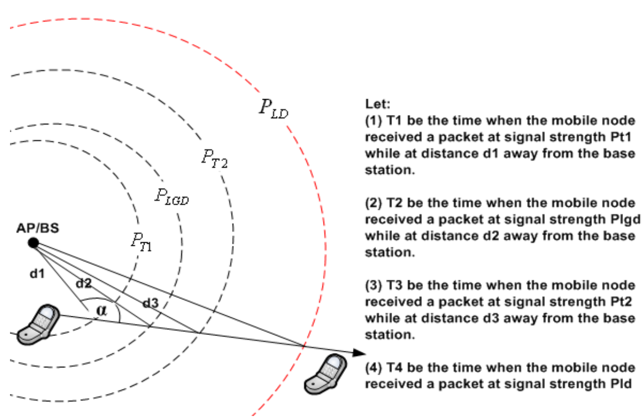

Fig. 2 MN movement and signal strength

The prediction algorithm uses the tuples passed by the RSS Monitor. These are $(P_{T1}, T1)$, $(P_{LGD}, T2)$ and

$(P_{T2}, T3)$ (As depicted on Fig. 2). From Fig. 2, equations that lead to the estimation of the time when the signal strength will be at P_{LD} beyond which the MN will no longer be able to receive packets successfully can be deduced. For simplification of the equations, let $t_2 = T2 - T1$, $t_3 = T3 - T1$ and $t = T4 - T1$.

Time	Power level (Signal Strength)
T1	$P_r = P_{T1} = \frac{kP_t}{d_1^4}$ (4)
T2	$P_r = P_{LGD} = \frac{kP_t}{(d_1^2 + (vt_2)^2 - 2d_1 vt_2 \cos\alpha)^2}$ (5)
T3	$P_r = P_{T2} = \frac{kP_t}{(d_1^2 + (vt_3)^2 - 2d_1 vt_3 \cos\alpha)^2}$ (6)
At Link Down	$P_r = P_{LD} = \frac{kP_t}{(d_1^2 + (vt\ )^2 - 2d_1 vt\ \cos\alpha)^2}$ (7)

Where, $k = G_t G_r h_t^2 h_r^2 / L$

In solving the above equations for *t*, mathematical substitutions, eliminations of variables such as the velocity *v* of the MN and the angle *α*, are performed. The solution obtained is of the form $at^2 + bt + c = 0$ which is a quadratic equation. The constants *a*, *b* and *c* are as shown in (8), (9) and (10).

$$a = t_2 \beta \sqrt{P_{LD} P_{LGD}} \quad (8)$$

$$b = \sqrt{P_{LD}}\left(\sqrt{P_{T1}} - \sqrt{P_{LGD}} - t_2^2 \beta \sqrt{P_{LGD}}\right) \quad (9)$$

$$c = t_2\left(\sqrt{P_{LGD} P_{LD}} - \sqrt{P_{T1} P_{LGD}}\right) \quad (10)$$

Where,

$$\beta = t_2\left(\sqrt{P_{T1}P_{LGD}} - \sqrt{P_{LGD}P_{T2}}\right) + t_3\left(\sqrt{P_{LGD}P_{T2}} - \sqrt{P_{T1}P_{T2}}\right) \Big/ \left(t_2 t_3^2 - t_2^2 t_3\right)\sqrt{P_{LGD}P_{T2}}$$

From the solutions of the quadratic equation, the positive one is considered since it is of interest in a future prediction. Thus, an approximate amount of time left before the link actually goes down (breaks) is given by $t = -b + \sqrt{b^2 - 4ac} \big/ 2a$. Therefore, the time estimate as to when the link will be down (LD on PMAG) is as given by (11).

$$Time(LD) = T4 = T1 + t \quad (11)$$

3.2.1.3 Events scheduler

The events scheduler generates and sends event trigger signaling messages to the LMA and the MN. The signaling message sent to the MN instructs it to disconnect from the point of attachment with degrading signal strength. This aids the MN to start the layer-2 handover (scanning new channels, authentication, and re-association) to the new point of attachment at the earliest possible time. Thus, the MN is forced to disconnect at *Time(LD)* since there is no need for the MN to continue to remain attached to PMAG when the signal strength is below the receive threshold (*RXThresh)* or P_{LD}.

Moreover, the events scheduler sends a signaling message to facilitate a proactive layer-3 handover approach. When the LMA receives this signaling message from the events scheduler, it performs pre-registration for the MN and sets up a route to the candidate point of attachment (between LMA and NMAG) when a handover is imminent. The expressions below show how performing a proactive handover lowers the handover delay.

$$t_{PMIPv6} = t_{L2-L3} + t_{PBU} + t_{PBA} + t_{MN\_HNP\_Adv}$$

$$t_{Predictive\_PMIPv6} \approx t_{MN\_HNP\_Adv}$$

t_{L2-L3} is the latency for layer-2 to notify layer-3 of the MN's attachment. t_{PBU} and t_{PBA} accounts for the delay of the proxy binding update from the MAG and the proxy binding acknowledgement from the LMA. And, $t_{MN\_HNP\_Adv}$ is the delay incurred for the router advertisement that contains the home network prefix for the MN to configure the same home address throughout the PMIPv6 domain. In the case of a predictive PMIPv6 handover, the binding update process and pre-registration for the MN between the NMAG and the LMA is done in advance and hence technically the MN is in advance attached to the next MAG. It should however be noted that the total handover delay during which the MN is unable to receive any packets includes the layer-2 handover latency.

Finally, the events scheduler sends the LMA signaling messages that instruct the LMA to start bicasting, and stop bicasting such that bicasting is executed in a timely and accurate manner. Unlike in the previously proposed bicasting PMIPv6 solutions, the times to start and stop bicasting are correlated to the behavior of signal strength decay. To minimize the loss of in-flight packets, the proposed EB-PMIPv6 solution the LMA stops sending (routing) packets destined to the MN to PMAG slightly ahead of the time when the link will be down as shown by (12). Thus, at this time, a route from LMA to PMAG is cleared. Equation 12 is also considered to be a stop bicasting time.

$$t_{stop\_bicasting} = Time(LD) - \{t_{LMA-PMAG} + t_{PMAG-MN}\} \quad (12)$$

Where $t_{LMA-PMAG}$ is constituted by the transmission delay on LMA and the propagation delay from the LMA to PMAG; $t_{PMAG-MN}$ is constituted by the transmission delay on PMAG as well as the propagation delay from the PMAG to the MN.

On the other hand, bicasting starts marginally before stopping bicasting by a short time margin Δ_t ($\Delta_t \geq 0$) such that bicasting which results into an increased utilization of backhaul bandwidth occurs for a short period of time as was discussed earlier.

$$t_{start\_bicasting} = Time(LD) - \{t_{LMA-PMAG} + t_{PMAG-MN} + \Delta_t\}$$
(13)

The proposed EB-PMIPv6 also adds an extra layer of extra accuracy on the timely generation of event triggers discussed above by incorporating the use of confidence level indication. The events scheduler computes the confidence level using the signal strength measurements from the RSS monitor to assess the probability or likelihood that the link is actually going to break in the near future. Equation 14 below shows how the confidence level C is computed. The confidence level gives an approximate indication of how close the signal strength is to the *RXThresh_*.

$$C = \left(\frac{P_{LGD} - P_r}{P_{LGD} - P_{LD}} \right) * 100 \quad (14)$$

Where P_r, is the instantaneous power or signal strength received at the MN. From (14), when $P_r \rightarrow P_{LGD}$, then $C \rightarrow 0$; and as $P_r \rightarrow P_{LD}$, then $C \rightarrow 100$.

3.2.1.4. Rollback facilitator

The rollback facilitator's main function is to signal to the LMA when the opposite of the prediction in the signal strength occurs so that the LMA can release the resources that were setup in preparation for the MN's handover. The route to the next anticipated point of attachment is cleared. The encapsulator as well as the binding cache entry for the MN is removed so as to conserve the network elements resources such as memory.

3.2.2. EB-PMIPv6 LMA Modifications

The EB-PMIPv6 design components on the LMA assist in performing operations that are coordinated by the EB-PMIPv6 components on the MAG side. These are facilitation of: 1) simultaneous bindings at the LMA to enable bicasting, and the encapsulation of packets to more than one MAG. 2) proactive layer-3 handovers by supporting the in-advance binding update process as well as the MN's routing state update. The proposed EB-PMIPv6 modifications on the LMA side are depicted in Fig. 3.

The classifier classifies and routes the signaling messages appropriately to either the Bicasting Trigger Generator or the Pre-routing update facilitator. The Pre-routing update facilitator ensures that the MN is pre-registered and sets up a route between LMA and NMAG in advance and ensures that the MN is pre-inserted into the binding cache list.

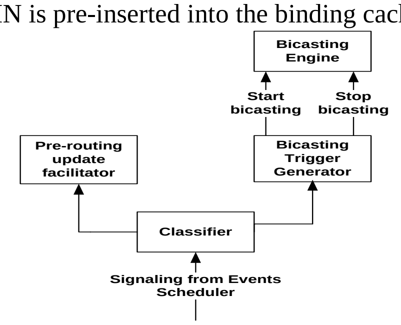

Fig. 3 EB-PMIPv6 Design on the LMA side

Lastly, the Bicasting Trigger generator generates triggers to start and stop bicasting. The Bicasting engine is responsible for performing the actual packets duplication and then encapsulates them in an IP-in-IP tunnel to both the PMAG and NMAG during the bicasting period. Thus during bicasting, a MN has two simultaneous bindings in the LMA binding cache entry list associating it to PMAG and NMAG. Packets destined for the MN that arrive at NMAG (Next (Candidate) MAG) during the layer-2 handover are buffered at NMAG and sent to the MN as soon as it attaches.

3.2.3. Signaling flow

The overall flow of signaling messages and operations that have been discussed in detail in the preceding sections and subsections are collectively shown in the message sequence chart in Fig. 4.

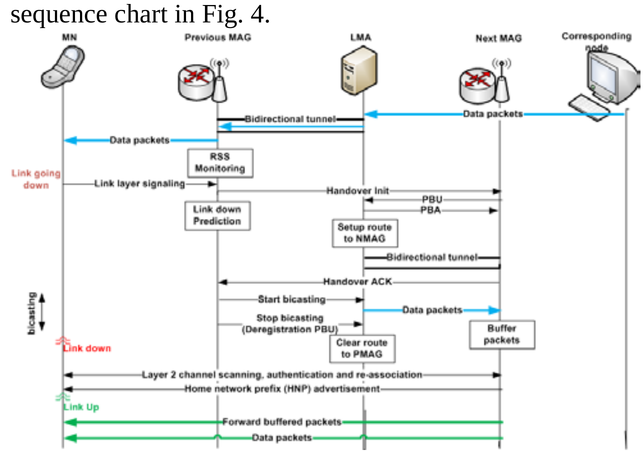

Fig. 4 EB-PMIPv6 handover signaling and operations

In this solution, the RSS is monitored and its decaying pattern is used to predict an estimate of the time at which the link down event on PMAG will be. The link down time estimate is then used to schedule and execute the bicasting operation very close to the link down event such that bicasting stops just before the signal strength goes below the receive threshold. It can be observed from Fig. 4 that, when a handover is imminent (when signal strength is at the LINK_GOING-DOWN threshold), after the binding update process a route to NMAG is setup but packets are not immediately sent. Packets are only routed to NMAG after the bicasting start trigger. Packets destined to the MN that reach NMAG during the time when the MN is performing a layer-2 handover as shown are buffered on NMAG. As soon as the MN attaches to NMAG, NMAG sends a router advertisement that includes the MN's home network prefix for the MN to configure an IP address. Packets that were being buffered on NMAG are then sent to the MN to continue with its ongoing communications.

4. Simulation setup

NS-2 is used in carrying out the simulations for comparing the proposed EB-PMIPv6 to the original PMIPv6, B-PMIPv6 [9, 10], and PB-PMIPv6 [13] in terms of handover performance as well as the network resources utilization.
Each MAG is collocated with an IEEE 802.11 (WLAN) access point (AP). The WLAN access points AP1 and AP2 provide the MN with wireless connectivity in the PMIPv6 domain with partially overlapping areas of coverage. The router RT is not modified and performs standard IP routing. The duplex links bandwidth and delays on the wired network are as depicted in the network model in Fig. 5.

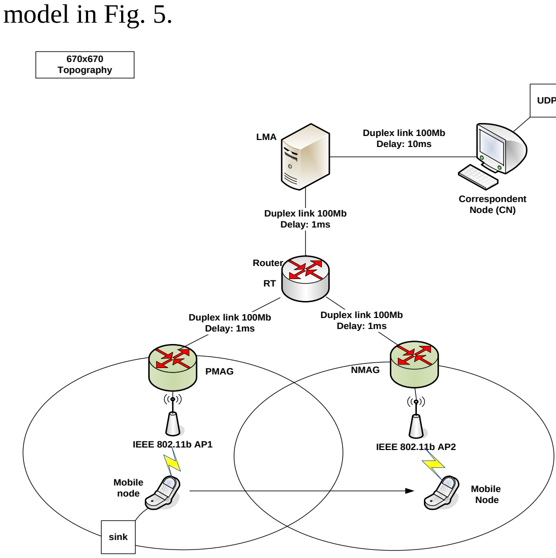

Fig. 5 Simulation network model setup

The correspondent node (CN) sends constant bit-rate (CBR) packets of size 1000 bytes every 0.001s (CBR packet interval) over User Datagram Protocol (UDP) to the MN to emulate a real-time traffic stream. A very short CBR packet interval of 0.001s was used in the simulations so as to approximate the handover delay accurately as packets are received by the MN just before the link breaks on PMAG and as soon as the link goes up on NMAG.

5. Results and Analyses

5.1. Handover performance

For the result presented in Fig. 6, to simulate a handover from PMAG to NMAG, at 1 sec, the MN began to move from PMAG to NMAG at a uniform velocity of 30m/s. The data used to plot the graph is extracted from the simulation trace file in the interval 13 seconds to 15.5 seconds within which the handover occurs. The break in reception of packets indicates the duration whereby the MN was not able to receive packets from PMAG and handing over to NMAG, and it is referred to as the handover delay.

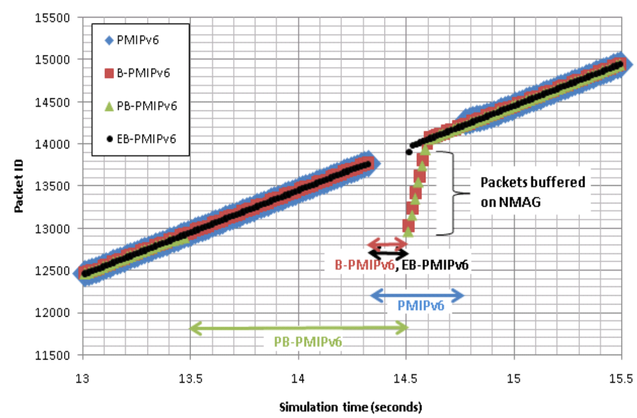

Fig. 6 CBR packets received by the MN

From Fig. 6, it can be observed that B-PMIPv6, and the proposed EB-PMIPv6 attain a much shorter handover delay than PMIPv6. This is because B-PMIPv6 and EB-PMIPv6 employ a predictive handover mechanism as opposed to the reactive mechanism used by PMIPv6. Furthermore, for B-PMIPv6 and EB-PMIPv6 the MN is able to receive packets through PMAG till the link breaks and immediately after attaching to NMAG.
On the other hand, even though PB-PMIPv6 also uses a predictive handover mechanism, the MN takes a much longer time without receiving packets. This is primarily because PB-PMIPv6 stops routing packets to PMAG as soon as a bidirectional tunnel is established between the LMA and the NMAG. This is done regardless of whether the signal strength is still strong enough to deliver packets from PMAG to MN without errors. Thus, it is observable

that PB-PMIPv6 can incur even longer handover delays at lower MN speeds (e.g. pedestrian speeds). However, it can perform better at higher MN speeds since the time from when PB-PMIPv6 stops bicasting (stops routing packets to PMAG) to when the MN attaches to NMAG shortens as the speed at which the MN moves when performing a handover increases.

It can further be observed that the utilization of the buffer on NMAG aids B-PMIPv6, PB-PMIPv6 and EB-PMIPv6 to incur lower packet loss after redirecting packets at the anchor point (LMA) to NMAG during the handover before the MN re-attaches to the network. Lastly, since PMIPv6 redirects packets to NMAG after MN attaches to NMAG a significant amount of packets are dropped on PMAG. It should however be observed that for B-PMIPv6, the MN receives duplicate packets which depicts an inefficient backhaul link usage, and networking infrastructure.

5.2. Application Throughput on MN

The plots presented in Fig. 7 show the throughput performance for each of the mobility schemes under evaluation as the MN performs a handover at 30m/s.

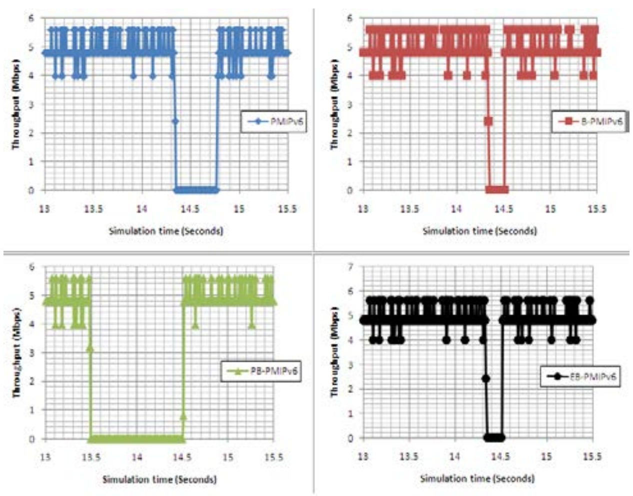

Fig. 7 MN throughput for PMIPv6, B-PMIPv6, PB-PMIPv6 and EB-PMIPv6

It is observable from the above plots that for the PMIPv6, the throughput stays at zero for a longer duration that B-PMIPv6 and the proposed EB-PMIPv6. This is caused by the reactive handover approach in PMIPv6 whereby layer-2 and layer-3 handover operations are carried out after losing connectivity from PMAG. Whereas for B-PMIPv6, PB-PMIPv6 and EB-PMIPv6, the layer-3 handover operations are performed in advance, thus eliminating their latencies from the total handover delay incurred. This is why the MN starts receiving packets earlier than in the case of PMIPv6.

It should however be noted that, even though PB-PMIPv6 employs the proactive handover approach to lower handover delays, PB-PMIPv6 stops sending packets to MN through PMAG much earlier when the MN would still be able to receive packets without errors.

5.3 MN Speed Impact on Handover Performance

Fig. 8 depicts the handover delay incurred when an MN performs a handover at different MN speeds ranging from 10m/s to 90m/s. As mentioned in the previous sections, in this study, the handover delay is the time incurred by the MN without receiving CBR packets from either PMAG or NMAG.

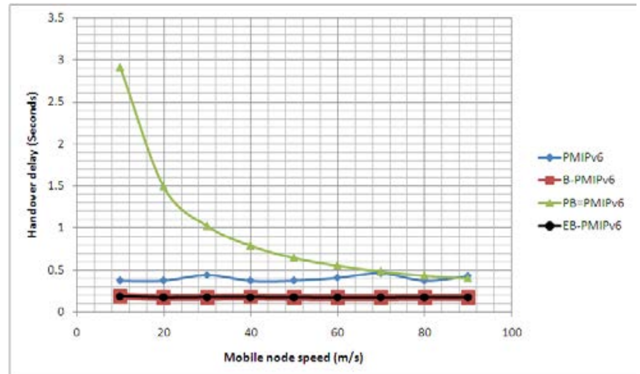

Fig. 8 MN speed impact on Handover delay

It can be observed that PB-PMIPv6 incurs much higher handover latency at low MN speeds. This is because PB-PMIPv6 stops routing packets to PMAG as soon as the layer-3 handover has been completed after the LINK_GOING_DOWN trigger has been generated. The time duration from when the LINK_GOING_DOWN trigger is generated on PMAG to the time when the MN successfully attaches to NMAG is longer when the MN is traversing from PMAG to NMAG at a low speed. This time duration shortens as the MN's speed increases when traversing from PMAG to NMAG. Therefore, for PB-PMIPv6 the time the MN takes without receiving CBR packets from either PMAG or NMAG decreases as the MN speed increases.

It can further be observed that PMIPv6 incurs much higher handover latency that B-PMIPv6 and the proposed EB-PMIPv6. This is mainly attributed to the fact that PMIPv6 uses a reactive approach to handovers.

It can also be observed that for PMIPv6, B-PMIPv6 and EB-PMIPv6, the handover delay is not significantly affected by to the MN speed. This is mainly attributed to the fact that, for these mobility schemes, packets are sent to the MN through PMAG till the signal strength decays to the receive threshold (*RXThresh_*) as well as through NMAG as soon as both the layer-2 and layer-3 operations are completed. Therefore, the time incurred without receiving packets at the MN is determined by the length of the handover delay. Now, the handover delay is dependent on the signaling carried out to perform the handover operations. And, PMIPv6 being a network-based mobility management solution, all mobility-related signaling is handled by the network elements (MAGs and LMA). Thus, the signaling is not dependent on the MN speed. This is why the handover latency does not show a direct relationship with the speed of the MN when traversing from PMAG to NMAG.

5.4. Network Resources Usage

5.4.1. Buffer usage

Bicasting schemes discussed in this paper make use of the proactive handover approach whereby during the handover, the LMA redirects the packet flow destined to the MN to the NMAG in advance. NMAG buffers packets if the MN handover operations are still pending completion. The plot in Fig. 9 shows the variation in buffer space requirement when the MN transits from PMAG's subnet to NMAG's subnet at different MN speeds.

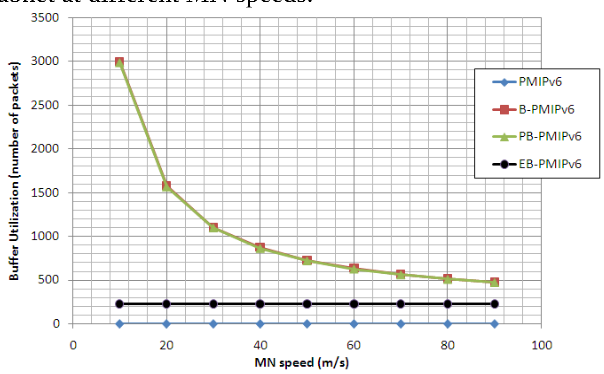

Fig. 9 Buffer usage at different MN speeds

PMIPv6 does not utilize the buffer on NMAG since packets are only redirected to NMAG after a successful handover as a reactive approach is used. The proposed solution; EB-PMIPv6 utilizes much less buffer space than B-PMIPv6 and PB-PMIPv6. This is because for EB-PMIPv6, the bicasting process is always timed to be close to the link down event on PMAG which consequently shortens the time taken buffering packets on NMAG. And, this lowers the chances of buffer overflows especially if a large number of MNs simultaneously perform a handover requiring packet buffering. Furthermore, for EB-PMIPv6 the number of packets buffered is almost constant regardless of the speed of the MN. This is because the duration in which packets need to be buffered is constant. This is the time in which the MN performs the layer-2 handover.

On the other hand B-PMIPv6 and PB-PMIPv6 route packets to NMAG when the handover is imminent. This implies that if the MN moves from PMAG to NMAG at a low speed, the duration from when buffering starts (when the handover is imminent on PMAG) till the MN attaches to NMAG for buffered packets to be released elongates. Hence why the amount of buffer space required is higher at lower MN speeds. Consequently, NMAG's buffer space requirement lowers at higher MN speeds.

5.4.2. Backhaul link usage

The next figure, Fig. 10 shows the backhaul bandwidth utilization in each of the mobility solutions when an MN traverses from PMAG's subnet to NMAG's subnet at speeds of 10m/s, 30m/s, 50m/s and 70m/s. The backhaul link usage statistics have been collected from the full-duplex link between the LMA and the Router (RT) on Fig. 10 (Simulation network model setup) which is the path that the duplicated packets traverse from the LMA to the MAGs (NMAG and PMAG). Since schemes evaluated are based on PMIPv6, the LMA encapsulates packets in an IP in IP tunnel from the LMA to the MAGs, thence packet size increases to 1040 bytes to accommodate the encapsulation header. Therefore, without bicasting the LMA sends an 8.32 Mbps stream onto the backhaul link.

It can be observed that for PMIPv6, the utilization of backhaul link remains flat during the handover since there is no alteration of the packets in terms of size or duplication by the LMA. It can also be deduced that as the MN speed increases, B-PMIPv6's utilization of the backhaul bandwidth decreases. This is because the bicasting period shortens as a result of the time period between starting bicasting (when LINK_GOING_DOWN is triggered) and the stop bicasting (when the LINK_UP is triggered) lowering. However, for PB-PMIPv6 and the proposed EB-PMIPv6 the length of the bicasting duration (which results into an increase in backhaul bandwidth usage) is shorter than in B-PMIPv6 and is independent of the MN speed.

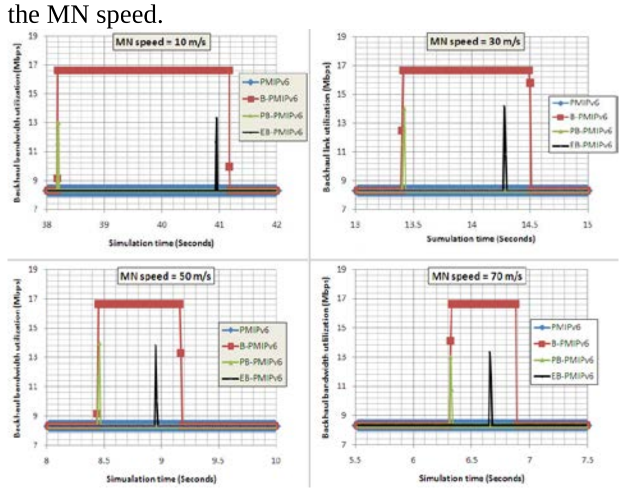

Fig. 10 Backhaul bandwidth utilization for different MN speeds

It can further be seen that for the proposed EB-PMIPv6, the bicasting operations are executed as close as possible to the LINK_DOWN event on PMAG regardless of the MN speed since the signal strength is used to determine the scheduling instances for the bicasting operations. This gives the proposed solution an advantage over B-PMIPv6 and PB-PMIPv6 because the amount of buffer space on NMAG is kept minimal regardless of the MN speed.

5.4.3. Duplicate packets transmitted on the network

In this subsection, an assessment on the number of duplicate packets received by the MN is performed. As was mentioned earlier, reception of duplicate packets is undesirable. If UDP is the transport protocol used, then it is required that the upper layers of the MN protocol stack provide a mechanism to eliminate duplicate packets to avoid hiccups in the application being consumed. However if TCP is used, it will discard the duplicate packets with the aid of sequence numbers. Nonetheless, higher numbers of packet duplicates at the MN indicate an inefficient usage of the network infrastructure since the packet duplicates at the MN need to be discarded. Fig. 10 below shows the number of packets that are received twice (duplicate) by the MN when an MN performs a handover from PMAG to NMAG at MN speeds ranging from 10 m/s to 90 m/s.

As depicted in Fig. 11, with B-PMIPv6, the MN receives a substantial amount of packet duplicates due to the bicasting duration which elongates at lower MN speeds and shortens at higher MN speeds. On the other hand, with PB-PMIPv6 and the proposed EB-PMIPv6 packet duplicates that reach the MN are very low (on average 3 packets). This is because the bicasting for EB-PMIPv6 and PB-PMIPv6 is transient. Furthermore, it is observable that the number of packet duplicates that reach the MN are almost constant regardless of the MN speed. This is because as shown in Fig. 11, the bicasting duration for PB-PMIPv6 and EB-PMIPv6 is not influenced by the MN's speed. Lastly, for PMIPv6, the MN receives no packet duplicates since packets are not duplicated before, during or after the handover.

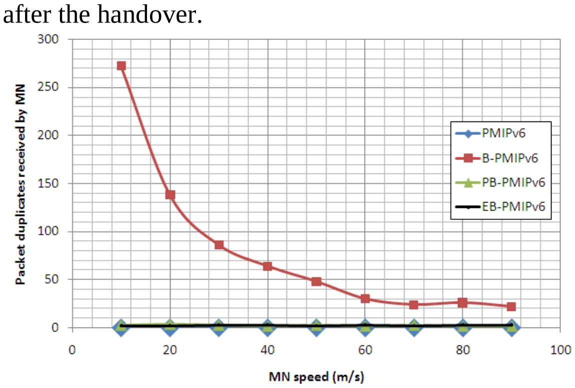

Fig. 11 Packet duplicates received by MN

5.5. Signaling overhead

Lastly, this subsection presents an evaluation of the signaling overhead incurred in the mobility schemes under evaluation. The number of MNs is varied from 1 to 10 to identify how the number of MNs simultaneously performing a handover affects the signaling overhead. Signaling overhead is an important performance metric to evaluate since signaling messages consume the scarce bandwidth in wireless networks. Secondly, an increased signaling overhead impacts the handover performance (handover delay and packet loss). Fig. 11 below shows the signaling overhead in bytes that occurs as MNs simultaneously perform handovers moving from PMAG to NMAG.

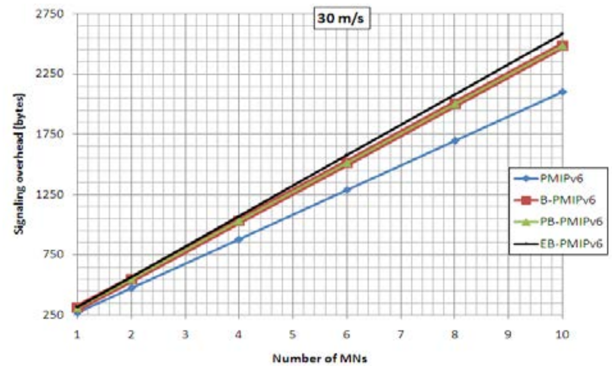

Fig. 12 Signaling overhead as MNs increase

Generally, it can be seen that, as MNs increase, the signaling overhead increases. PMIPv6 incurs the least signaling overhead among the schemes under evaluation. On the other hand, B-PMIPv6 and PB-PMIPv6 incur higher signaling overhead than that of PMIPv6. This is attributed to the increase in signaling messages that are required for anticipation of the handover in order to perform proactive handovers. These are the handover initiate and acknowledgement (HI, HAck)) messages. As for the bicasting, the PMIPv6 signaling messages (PBU and Dereg-PBU) are piggybacked to trigger bicasting to start and stop. It should however be noted that the signaling overhead incurred by B-PMIPv6 is similar to that of PB-PMIPv6. This is because; the only difference in the handover signaling is the order in which the signaling messages are sent.

Lastly, it can be observed that the proposed EB-PMIPv6 incurs slightly more signaling overhead than B-PMIPv6 and PB-PMIPv6. One of the essential EB-PMIPv6 objectives is to have control and coordination on the bicasting operations to achieve timely and accurate execution. Similar to B-PMIPv6 and PB-PMIPv6, in EB-PMIPv6, to stop bicasting the PMIPv6 signaling Dereg-PBU is piggybacked to signal to the LMA to stop bicasting packets destined to MN. However, additional signaling overhead is incurred to accommodate the start bicasting message.

6. Conclusion

This paper has investigated issues in the bicasting solutions for PMIPv6. With the challenges identified, this study led to the development of an enhanced bicasting scheme for PMIPv6 (EB-PMIPv6). The main objective of the EB-PMIPv6 is to improve the handover performance of PMIPv6 whilst also paying attention to the efficiency in utilization of the scarce and shared network resources (backhaul bandwidth and network elements buffer space). To attain the objectives, the proposed solution employs timely and accurate link-layer triggers that are generated based on the received signal strength (RSS). The link layer triggers provide a coordinated functionality to facilitate timely execution of handover operations such that the objectives are attained. All in all, the experimental results and analyses carried out show that the proposed EB-PMIPv6 scheme indeed improves the PMIPv6 handover performance whilst also efficiently utilizing the scarce and limited network resources. Therefore, the solution possesses customer-oriented as well as network-operator based advantages. This however comes at a cost of a slightly increased signaling overhead.

Acknowledgments

This work has been supported by the Faculty of Science and Technology, Department of Mathematics and Computers Science (MACS) at the National University of Lesotho

References

[1] M. Olsson, S. Sultana, S. Rommer, L. Frid and C. Mulligan, SAE and the Evolved Packet Core, Driving the Mobile Broadband Revolution. Elsevier, 2009.
[2] R. Koodli, "Mobile IPv6 Fast Handovers," IETF RFC 5568, July 2009.
[3] E. S. Gundavelli, K. Leung, V. Devarapalli, K. Chowdhury and B. Patil, "Proxy Mobile IPv6," IETF RFC 5213, August 2008.
[4] M. Dinakaran and P. Balasubramanie, "Performance Analysis of Various MIPv6 Protocols," European Journal of Scientific Research, Vol. 49, No. 3, pp. 403-414, 2011.
[5] Motorola, "Technical Whitepaper: Long Term Evolution (LTE): A Technical Overview," 2007.
[6] K. Kong, W. Lee, Y. Han, M. Shin and H. You, "Mobility management for all-IP mobile networks: Mobile IPv6 vs. Proxy Mobile IPv6," IEEE Wireless Communications, Vol. 15, No. 2, pp. 36-45, April 2008.
[7] L.A.Magagula, "A Network-based Coordination Design for Seamless Handover between Heterogenous Wireless Networks," PhD Thesis, University of Cape Town, December 2010.
[8] H. Yokota, K. Chowdhury, R. Koodli, B. Patil and F. Xia, "Fast Handovers for Proxy Mobile IPv6," IETF RFC 5949, September 2010.
[9] J. Kim, S. Koh, N. Ko and S. Hong, "PMIPv6 with bicasting for IP handover," Third International Conference on Convergence and Hybrid Information Technology (ICCIT 2008), pp. 793-796, November 2008.
[10] J. Kim, S. Koh and N. Ko, "B-PMIPv6: PMIPv6 with bicasting for soft handover," 11th International Conference on Advanced Communication Technology, pp. 218-221, February 2009.
[11] M. S. Bargh, B. Hulsebosch, H. Eertink, G. Heijenk, J. Idserda, J. Laganier, A. R. Prasad and A. Zugenmaier, "Reducing handover latency in future IP-based wireless networks: Proxy mobile IPv6 with simultaneous bindings," IEEE Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM 2008), pp. 1-10, June 2008.
[12] W. Guan, X. Ling, X. Shen and D. Zhao, "Handoff trigger table for integrated 3G/WLAN networks," International Conference on Wireless Communications and Mobile Computing, pp. 575-580, 2006.
[13] J. Kim and S. Koh, "Partial bicasting with buffering for proxy mobile IPv6 handover in wireless network," Journal of Information Processing Systems. Vol. 7, No. 4, pp. 627-634. 2011.
[14] National Institute of Standards and Technology (NIST), "The Network Simulator NS-2 NIST add-on - Mac 802.11," January 2007.
[15] L. Qin and T. Kunz, "Increasing packet delivery ratio in DSR by link prediction," Proceedings of the 36th Annual Hawaii International Conference in System Sciences, January 2003.

Lebajoa Mphatsi received his Bachelor of Engineering in Computer Systems and Networks degree in 2009 from The National University of Lesotho. He then completed his Master of Science degree in Electrical Engineering at the University of Cape Town - South Africa, in December 2012. He is currently employed as a lecturer in Computer Science and Engineering at the National University of Lesotho, Department of Mathematics and Computer Science (MACS). His research interests include mobile radio communications, wireless broadband technologies and cross layer design optimizations to mention a few.