An Adaptive Scheme Supporting Seamless Handovers over Mobile IPv6 for Video Streaming Applications

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***Abstract*—The movement of nodes within wireless networks often results in a change in the node's point of attachment, resulting in broken data paths from source to destination. The latency and packet loss associated with this often result in severe quality degradation for many real-time applications. Existing improvements to Mobile IPv6 are inadequate to support seamless handovers when streaming video. However, our philosophy is that a combination of existing techniques to improve handover and to adapt to changing wireless network conditions, coupled with improved communication within the protocol stack, is likely to result in a scheme that supports seamless handovers. This paper presents an adaptive mobile video streaming scheme together with an implementation to assess the scheme.**

***Index Terms*—Mobile IPv6, IEEE 802.11, Seamless Handover, Adaptive Streaming**

I. INTRODUCTION

Wireless local area networks (WLANs) have become increasingly popular as they enable nodes to maintain network connectivity as they roam within a coverage area. Wireless nodes already form a major portion of all nodes connecting to the Internet, and in the future, are likely to form the majority of all connecting nodes [2]. Further, voice, video and audio applications are becoming the norm for user expectations of applications on today's networks. If wireless access is to account for a significant portion of network accessing nodes in the future, it is of paramount importance to provide adequate multimedia support on wireless networks.

However, the movement of nodes often requires the change of the node's point of attachment to the network. This change in attachment results in a broken data path from source to destination. Mobile IP has emerged as the prevalent mobility management scheme to address such issues. Although Mobile IP maintains the connectivity of mobile nodes, the disruption often results in drastic quality degradation in the node's IP stream. This is unacceptable for many real-time multimedia applications that have strict application requirements.

This research aims to address this problem. For simplicity, we focus on a specific type of application (video-on-demand streaming) on a specific network architecture (infrastructure mode IEEE 802.11g WLAN). First, an overview of relevant technologies and related work is presented (Mobile IPv6, IEEE 802.11 WLANs, and video streaming applications). Thereafter, an adaptive mobile video streaming scheme to support seamless mobility in WLANs is presented. We then provide an implementation of our scheme to assess its performance and finally conclude.

II. BACKGROUND

A. Mobile IPv6

The Internet Protocol (IP) provides packet routing and delivery services for the Internet and private networks. It is a connectionless, best-effort packet switching protocol. IP version 6 (IPv6) is the new version of IP intended to replace the current IP version 4 (IPv4) [17]. Mobility support in IPv6 enables packets to be rerouted to a mobile node (MN) when it moves away from its home IP subnet. This extension to IPv6 is known as Mobile IPv6 (MIPv6) [9, 17]. In essence, this protocol serves to maintain the connectivity of IP mobile nodes as they move from one wireless point of attachment to another in a different subnet.

Each MN is assigned a permanent IPv6 address (its *home address*). The IP subnet indicated by this address is the MN's home subnet. Conventional IP routing mechanisms will deliver packets destined for the MN to the MN's home subnet. By definition, a mobile node can change its point of attachment from one IP subnet to another. The mobile node's current location on a foreign subnet is defined by its *care-of-address*. This address is only associated with the MN while it is visiting that particular foreign subnet. The association of a mobile node's *home address* and *care-of-address* is known as a *binding*. The node with which the MN is communicating is called a correspondent node (CN) [9, 17].

When a MN moves to a new point of attachment on a new subnet, its CN will continue to send packets to its home subnet. Further, it can no longer use its *home address* to send packets in this foreign subnet. Therefore, the MN needs to acquire a *care-of-address* in the foreign subnet. It can then inform its home subnet and CN about this *binding* between its *home address* and new *care-of-address* [15].

A MN attaches to a network through an access router (AR). An AR on the MN's home subnet (known as the MN's *home agent*) maintains a list of its current bindings. Any packets that arrive on the home subnet addressed to the MN are then intercepted by the *home agent* and tunnelled to the MN at its current *care-of-address*. Once the CN determines the MN's *care-of-address*, it can cache it and use it to route packets destined for the MN directly to it, bypassing the *home agent* completely [9, 17].

When a MN moves from one IP subnet to another a MIPv6 handover must occur. The MN cannot receive IP packets at its new point of attachment until this handover is complete. The MN must first establish a physical link to the new IP subnet. This is known as a link-layer handover. This involves a break in the connection to the current access point and the establishment of a connection to a new access point. Consequently, there is a disruption in the communication of the MN. Mobile IP is not aware of link-layer handover as it was designed to operate over heterogeneous networks (networks based on different technologies) and functions on the network layer.

The next stage of a MIPv6 handover is the movement detection stage. The MN detects that it has moved to a new subnet by analysing the *router advertisement* sent by the AR on the new link. The AR sends *router advertisements* periodically [15]. If the MN does not receive a *router advertisement* at the frequency indicated by the *router advertisement* from the old AR, it can send a *router solicitation*. The new AR will respond with an appropriate advertisement. Since the MN does not have to wait a full period for the next *router advertisement*, the *care-of-address* establishment is accelerated. Configuration information may also be included with the *router advertisement* (such as a list of *care-of-addresses* available to the MN). A registration lifetime is also sent with the *router advertisement*. This is the maximum time that the MN is allowed to remain registered to that AR [15, 17]. The MN must then establish a *care-of-address*. First, it needs to verify the uniqueness of its link-local address. Then it may use address auto-configuration to form its new *care-of-address* [15].

Once the MN has a new *care-of-address* it must inform its *home agent* and CNs. This is called MIPv6 handover registration. The MN sends a *binding update* (indicating the *binding* between its new *care-of-address* and *home address*) to its *home agent*. The MN can request an acknowledgement. This reply from the *home agent* is a *binding acknowledgement*. Thus, the *home agent* is always aware of the MN's current point of attachment to the network [15, 17].

B. IEEE 802.11 WLANs

IEEE 802.11 is a family of specifications for wireless local area networks (WLANs) developed by a working group of the Institute of Electrical and Electronics Engineers (IEEE). The 802.11 Standard independently defines both the physical layer and data-link layer of the OSI Reference Model (layer 1 and 2) [5].

The original IEEE 802.11 standard provides 1-2 Mbps transmission in the 2.4 GHz band using either frequency hopping spread spectrum (FHSS) or direct sequence spread spectrum (DSSS). Due to the fairly low data rates, this standard is largely outdated. The IEEE 802.11b ("baseline") standard is backward compatible with 802.11. Its frequency band is subdivided into several channels. Standard DSSS together with advanced coding techniques allow data rates of up to 11 Mbps to be achieved. IEEE 802.11g ("going beyond b") allows data rates of up to 54 Mbps to be achieved in the 2.4 GHz band using orthogonal frequency division multiplexing (OFDM) [1]. It is compatible with IEEE 802.11b, but has a reduced range at its maximum bit rate. Several other specifications exist in the 802.11 family. They will not be discussed further here, as the IEEE 802.11g specification introduced here is used in this research.

IEEE 802.11g enables two operational modes: an ad hoc mode where there is no central point and an infrastructure mode where all communication occurs via an access point (AP) [1, 15]. An AP has at least one wireless interface and one wired interface. It serves as a bridge between the wired network and the WLAN.

For a MN to connect to an AP, it must first discover nearby APs, select one and then attach to it. To find out what APs are available in the region, a MN can either listen passively for *beacon frames* or send *probe request* frames and wait for *probe responses* from APs. Once the MN selects the most suitable AP to attach to based on its selection criteria, it goes through an authentication process. After the MN is authenticated, it begins an association process, where the MN and AP exchange information about their capabilities. Only after this association process can the MN transmit or receive data frames. The total time taken for the MN to disconnect from an AP and re-connect to another AP is known as the link-layer handover latency.

C. Video Streaming

Video streaming refers to the real-time transmission of live or stored video over a network. Examples include news retrieval, webcasting, HDTV (High Definition Television) and video on demand. The main requirement of video streaming is sustained high visual quality, and not application interactivity.

Delay variation (jitter) is caused by the build up of buffers in the routers during periods of increased traffic, and by changes in routing. The amount of network jitter an application can tolerate depends predominantly on the nature of the application tasks. Applications with strict delay requirements can only afford minimum delay variation. Video streaming applications can make use of an initial delay to build up a receiver playout buffer. This allows it to accommodate quite high jitter values, which translates to bounded data loss rates. The user expectation of data loss is that it should be lower than 2-3 % [14]. However, this initial buffer is finite and it is possible for a MN to undergo several handovers during the lifetime of a video streaming application. So this initial buffer is often insufficient to guarantee no disruptions to the application.

Streaming media may be encoded with a single bit rate level or with multiple bit rate levels. With multiple encoded bit rate levels a streaming media server can dynamically alter the bit rate of the video being streamed according to changing network conditions [11].

III. RELATED WORK

The time taken for a MIPv6 handover to complete is called the handover latency. This includes the time taken for movement detection, *care-of-address* establishment and handover registration. In addition, the time taken for link-layer handover is finite and non-zero, and contributes to MIPv6 handover latency. In many cases, handover latency severely degrades the IP stream of MNs. Therefore, various extensions to MIPv6 and new protocols have been proposed to improve the IP connectivity of MNs. These include (but are not limited to) hint-based movement detection, Hierarchical Mobile IPv6 (HMIPv6) and Fast Mobile IPv6

(FMIPv6). Each of these is briefly introduced below, with more detail given on FMIPv6 as this is particularly relevant to our implementation.

Hint-based movement detection methods make use of hints generated during link-layer handovers. If the Mobile IP layer were made aware of such a hint it could force the MN to broadcast a *router solicitation*. This enables faster handovers than advertisement-based methods, as the movement detection time is reduced, but wastes bandwidth due to increased signalling. This could become a significant drawback on a network with many access points and MNs.

Hierarchical schemes separate mobility management into intra-domain mobility and inter-domain mobility. The performance impact of mobility is reduced by handling local movement locally and hiding this from the *home agent* [7, 20]. A hierarchy of ARs is created between the *home agent* and the MN. Tunnelling can be changed in the AR hierarchy, without the MN having to register with the *home agent*. Thus, the signalling overhead and delay concerned with the *binding update* (and consequently the handover registration process) in MIPv6 is reduced. This allows MIPv6 to scale better for quick handovers. However, HMIPv6 is insufficient to enable seamless handovers because the total handover latency is still significant.

FMIPv6 sets up services for the MN on the new AR before the movement of the MN [8, 10]. It enables a MN to request information on neighbouring access points (APs) and the subnets behind them. A MN does this by sending a *router solicitation for proxy advertisement.* The currently default AR responds with a *proxy router advertisement*. A MN can then anticipate handover through the use of link-layer hints. A hint is initiated in the link-layer to begin the network layer handover before the link-layer handover is complete. The MN sends a *fast binding update* to its current AR (PAR) with its current *care-of-address* and the new AR (NAR) it plans to switch to. The PAR sends a *handover initiate* message to the NAR, containing the identity of the MN. The NAR responds with a *handover acknowledge* message and the PAR sends a *fast binding acknowledgement* back to the MN. The MN is then ready to actually switch links. This type of handover is a predictive handover. FMIPv6 also defines a reactive handover scenario, where the MN was unable to anticipate handover so it reacts when the handover is already in progress. In this case the NAR sends the *fast binding acknowledgement* to the MN once the link-layer handover is complete. The PAR tunnels packets destined for the MN to the NAR (which then forwards the packets to the MN). The handover latency and disruption in the IP stream involved in FMIPv6 is considerably shorter than in MIPv6. Packet losses are also minimised since packets addressed to the old *care-of-address* are forwarded to the MN through the NAR. However, the handover latency that persists is still too long to enable seamless handovers for many real-time applications. Nevertheless, these improvements provide valuable support to such applications.

The solution we propose in the following sections is based on the work that has already been performed in [12].

IV. OUR SCHEME

The issues that affect the provision of adequate real-time multimedia support have been introduced in Section II. These include the handover latency and re-routing packet loss associated with MIPv6 handover; link-layer handover latency in the WLAN, and application requirements (acceptable delay, required throughput, etc.).

The challenge in providing real-time multimedia application support arises because no form of Quality of Service is guaranteed on any of the layers of the protocol stack in the system under consideration, so streams are unable to recover from disruptions introduced by MIPv6 handover. IEEE 802.11g provides functionality to allow reliable data delivery for the upper layers, over the physical and link layers. The delivery itself is based on a connectionless, best-effort delivery of medium access control layer data. There is no guarantee that delivery will be successful or that it will be provided at better than a specified data rate. MIPv6, which operates on the network layer, is also a best-effort service.

The requirements of an ideal streaming video handover scheme should be to:

1) reduce the packet losses caused by handover to avoid drastic quality degradation;
2) minimise the handover latency to reduce the impact of the handover on the application's throughput;
3) maintain the continuity of the application during the handover; and
4) probe the available bandwidth in the new wireless cell allowing the streaming video to adapt its quality to the new available bandwidth to avoid potential congestion.

Network layer mobility management techniques serve to minimise handover latency and reduce re-routing packet loss (packet loss due to broken data paths from source to destination) during handovers. Transport layer mobility management techniques are mainly proposed for reliable data transmission [16]. However, although the latency incurred during MIPv6 handover can be minimised, it cannot be completely eliminated [19]. In the case of WLANs, link-layer handover latency also persists. In addition, these existing mobility management techniques do not adapt to wireless characteristics such as frame loss rate, signal strength, or link-layer bit rate, in order to protect the quality of video streams from bad wireless conditions [11].

Our philosophy is to consider a cross layer approach supporting seamless handovers. A combination of existing techniques to enhance handovers, techniques to adapt to changing network conditions, and improved communication between the layers of the protocol stack is likely to result in improved handover performance [7, 13, 18].

It is possible for a streaming media server to adapt the video (encoded with multiple bit rate levels) being streamed to a MN based on changing network conditions. This allows us to manage the available bandwidth on the link effectively. We are then able to ensure that the MN always buffers enough frames to allow for a disruption in the data path during a possible future handover. The bit rate of the stream is reduced but the same data rate is maintained, effectively increasing the rate at which frames are delivered to the MN. However, the MN continues to view frames at the same rate. The "extra" frames are buffered and may be viewed during the handover period. When the handover is complete, the MN continues to receive packets via the new access router. If the completion of the MIPv6 (network layer) handover can be guaranteed before all the buffered frames are viewed, and packet loss is minimised, the video will continue streaming uninterrupted to the MN during and after the handover. Thus, the handover will appear seamless to the end user.

FMIPv6 is used to minimise re-routing packet loss and handover latency. Adaptive video streaming combined with FMIPv6 is the crux of our scheme.

Ideally, we want to be able to predict MN movements to guess whether handover is imminent. Then we may use our scheme to support the handover without adding unnecessary overhead to the network infrastructure. However, this is beyond the scope of our work. So, for simplicity, we assume that a handover will definitely take place at some point in the future. Thus, we work on the premise that a handover is always imminent and we always prepare for this handover. This assumption will not add any overhead to the network infrastructure, it simply implies that a user may be forced to view a video stream at a lower bit-rate than the capacity on the wireless link allows for. This cost is negligible for the analytical purpose of this work.

Our scheme is based on the widely accepted maxim that users prefer a reduced bit rate to packet losses when streaming video [4]. It satisfies the requirements of an ideal stream media handover scheme that have been identified in this paper.

V. IMPLEMENTATION

We have implemented a test-bed in order to evaluate the effectiveness of our scheme. This section describes our implementation.

The implementation consists of an infrastructure mode IEEE 802.11g WLAN on a gigabit Ethernet wired backbone. The architecture for the evaluation framework is illustrated in Fig. 1. The streaming video server is attached in the MN's home subnet for the sake of simplicity. The *home agent* also acts as a border router, with an interface to the global IPv6 network and another interface to the home subnet. The ARs in the foreign subnets have two interfaces. They are each connected to the backbone through a link layer switch and have wired links directly to 802.11g dedicated access points.

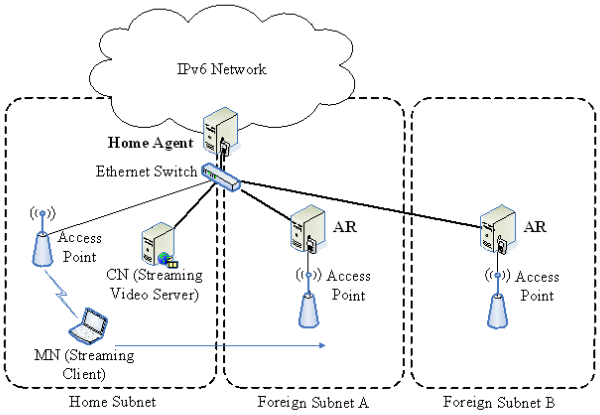

Fig. 1. Overview of the implementation architecture

For the purpose of our evaluation, stored video will be streamed to the client (a video on demand application). Two distinct versions of each video are encoded on the streaming media server: a single bit rate level version (for conventional MIPv6 handovers), and a multiple bit rate level version that includes several encoding layers (for our scheme). The streaming server may then stream this video at whatever specific bit rate the MN requests, based on network conditions. An algorithm is required to determine the optimal bit rate for the MN's stream, given the available bandwidth on the wireless link and a maximum disruption time during a future handover. The adaptive scheme implies a unicast system, where each MN requires its own copy of a video stream, as opposed to multicast, where one copy may be sent to a group of users.

Mobile IPv6 for Linux (MIPL) is a MIPv6 implementation developed by the GO-Core project at Helsinki University of Technology (HUT) [21]. MIPL 1.1 is a full kernel space implementation of the MIPv6 specification (internet draft 24), which does not support IPSec. MIPL 2.0 is a full implementation of the MIPv6 standard (RFC3775) [9]. The MIPL 2.0 implementation was selected to be used for our implementation because it is the most complete and robust implementation of MIPv6 available and a significant amount of technical support exists for it. In addition, the Network Research Team of the Louis Pasteur University has developed a FMIPv6 implementation (fmipv6.org) based on HUT's MIPL 2.0 [8, 22]. The goal of their project is to provide a fully compliant implementation of the FMIPv6 protocol specified in RFC4068 [10]. The fmipv6.org implementation has been used to extend the evaluation framework to support FMIPv6.

This framework supports MIPv6 and FMIPv6 handovers and an adaptive streaming media server. An analysis of the packet loss, handover latency and disruption time in the communications of the MN during a handover will provide a quantitative assessment of the performance of the proposed scheme. A more complete evaluation of our scheme should include user-perception techniques. Although such a qualitative method would be subjective and not very comprehensive, it would provide a crude indication of the effectiveness of our scheme.

VI. CONCLUSIONS AND FUTURE WORK

The focus of this research is on minimising the disruption time in the MN communications during handover and ensuring that the user does not perceive this disruption. The number of lost packets and the time required to complete the different handover protocols will have an impact on this, so our objective is to optimise the handover performance and to mask the effect of any disruption that persists.

As far as deployability is concerned, the major change to existing networks that is required is the modification to streaming media servers to support adaptive streaming. The server will have to manage the unicast stream to each MN it serves, dynamically establishing network conditions and adapting the stream accordingly. This is a considerable server-side overhead but does not introduce a significant change to the network infrastructure. Therefore, the associated overhead and economic impact of deploying this scheme is likely to be offset by its positive performance. While this is a cross-layer approach to supporting mobility, it is driven by the application layer so that its impact on network infrastructure is minimised.

We expect to obtain preliminary results from our evaluation framework shortly. Once these results are available, a fuller analysis of its effectiveness and practicability will be possible.

ACKNOWLEDGEMENTS

The authors would like to thank Telkom SA, Siemens, the National Research Foundation (NRF) and the Department of Trade and Industry (DTI) for supporting this research project.

REFERENCES

[1] ANSI/IEEE Std 802.11, "IEEE Standard for Information Technology – Telecommunications and information exchange between systems – Local and Metropolitan Area Networks – Specific Requirements – Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications – Amendment 4: Further Higher Data Rate Extension in the 2.4 GHz Band," IEEE Std 802.11g-2003, The Institute of Electrical and Electronics Engineers, Inc., June 2003.

[2] A. T. Campbell, J. Gomez-Castellanos, "IP Micro-Mobility Protocols," Mobile Computing and Communications Review, Volume 4, Number 4.

[3] H. Chaskar, "Requirements of a Quality of Service (QoS) Solution for Mobile IP," Internet Engineering Task Force (IETF), RFC3583, September 2003.

[4] N. Cranley, L. Murphy, P. Perry, "User-Perceived Quality-Aware Adaptive Delivery of MPEG-4 Content," Proceedings of *NOSSDAV '03*, June 2003.

[5] B. Furht, M. Ilyas, "Wireless Internet Handbook: Technologies, Standards and Applications," CRC Press, 2003.

[6] J. A. Garcia-Macias et al, "Quality of Service and Mobility for the Wireless Internet," Wireless Networks 9, pp 341-352, 2003.

[7] R. Hsieh, A. Seneviratne, H. Soliman, K. El-Malki, "Performance analysis on Hierarchical Mobile IPv6 with Fast-handoff over End-to-End TCP," Internet Performance Symposium Session: IPS-02.

[8] E. Ivov, T. Noel, "An Experimental Performance Evaluation of the IETF FMIPv6 Protocol over IEEE 802.11 WLANs," Proceedings of *WCNC 2006*, April 2006.

[9] D. Johnson, C. Perkins, J. Arkko, "Mobility Support in IPv6," Internet Engineering Task Force (IETF), RFC3775, June 2004.

[10] R. Koodli, "Fast Handovers for Mobile IPv6," Internet Engineering Task Force (IETF), RFC4068, July 2005.

[11] M. Li, F. Li, M. Claypool, R. Kinicki, "Weather Forecasting – Predicting Performance for Streaming Video over Wireless LANs," Proceedings of *NOSSDAV '05*, June 2005.

[12] M. K. Mathews, N. Ventura "An Adaptive Mobile Video Streaming Scheme over Mobile IPv6 for IEEE 802.11 LANs," Proceedings of *IST-Africa 2006*, May 2006.

[13] J. McNair, T. Tugcu, W. Wang, J. Xie, "A survey of cross-layer performance enhancements for Mobile IP networks," Computer Networks 49, pp 119-146, 2005.

[14] D. Miras et al, "A Survey of Network QoS Needs of Advanced Internet Applications – Working Document," Internet2 QoS Working Group, November 2002.

[15] N. Montavont, T. Noel, "Analysis and Evaluation of Mobile IPv6 Handovers over Wireless LAN," Mobile Networks and Applications 8, pp 643-653, 2003.

[16] Y. Pan, M. Lee, J. B. Kim, T. Suda, "An End-to-End Multi-Path Smooth Handoff Scheme for Stream Media," Proceedings of *WMASH '03*, September 2003.

[17] C. Perkins, D. Johnson, "Mobility Support in IPv6," Proceedings of *MOBICOM 96*, November 1996.

[18] V. T. Raisinghani, S. Iyer, "Cross-layer design optimizations in wireless protocol stacks," Computer Communications 27, pp 720-724, 2004.

[19] H. Soliman, "Mobile IPv6: Mobility in a Wireless Internet," Addison-Wesley, April 2004.

[20] H. Soliman, C. Castelluccia, K. El Malki, L. Bellier, "Hierarchical Mobile IPv6 Mobility Management (HMIPv6)," Internet Engineering Task Force (IETF), RFC4140, August 2005.

[21] "Mobile IPv6 for Linux," [Online] http://www.mipl.mediapoli.com/, 25 November 2005.

[22] "fmipv6.org," [Online] http://www.fmipv6.org/index.php/Main/HomePage, 25 January 2006.

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