Fast mobility in proactive routing protocols

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Abstract: This paper presents an innovative extension to routing protocols using a back-tracing technique to improve performance of handovers in wireless mesh networks. The main purpose of this extension is to minimize disconnection time and packets losses when mobility occurs. The proposed scheme requires some minor changes to the original proactive ad-hoc routing protocol, but does not impose any modification to the current IEE 802.11 MAC protocol. Some additional changes are also required to the handover signalling, in order to better optimize the process. The back-tracing mechanism is also able to reach route convergence to a minimum route length maintaining the throughput of data packets. The results of the proposed extension show that it is able to maintain the network throughput in wireless mesh networks during mobility, minimizing the packet losses.

Keywords: wireless mesh networks, back-tracing, route convergence.

1. Introduction

Wireless Mesh Networks aim to be a spontaneous type of networks [1] based on self-organization paradigms, where mesh routers are added in a self-forming way. Coverage increases automatically, allowing a continuous addition of terminals and a self-adapting topology. In the mesh infrastructure there are two types of devices: the Wireless Mesh Routers (WMR) and the Wireless Mesh Terminals (WMT). A WMR is the device that creates the transport network and enables the communication between the associated terminals in the same or in different Wireless Mesh Networks (WMN). A terminal can be any type of device with a WiFi interface, whether highly mobile or stationary. This includes smart phones, motor vehicles, roadside information stations, satellites, and desktop or hand-held computing devices. In the particular case of the WIP project [3], terminals will mostly be comprised of laptops or desktop computers and PDAs, all with WiFi support.

WMR are assumed to be mostly static and to have a vast set of resources available in terms of multiple wireless network interfaces and different types of antennas. They form the backbone of the network, while providing connectivity service to the several WMTs. To address communication inside the WMN, routing protocols need to be in place; these protocols must adjust and integrate completely to the specific aspects of these networks. Since WMN are self-organized and are aiming at the support of fast mobility terminals, routing protocols must be as simple and adaptable as possible, but at the same, must be robust and scalable. Various types of techniques were addressed in the literature related with mobility in wireless networks in several aspects such as routing, location and addressing. Since mobility management is directly related with the routing method used, there are several routing aspects that must be considered when dealing with mobility in WMN. Depending on which routing methods are in use, aspects such as distance between source and destination nodes and techniques of packets re-forwarding through the network in mobility situations must be present.

This paper proposes an extension to routing protocols using a back-tracing technique to improve performance of handovers in WMN. The main purpose of this extension is to minimize disconnection time and packets losses when mobility occurs. The back-tracing mechanism is able to reach route convergence to a minimum route length maintaining the throughput of data packets. The results of the proposed extension show that it is able to maintain the network throughput in wireless mesh networks during mobility, minimizing the packet losses.

The paper is organized as follows. Section 2 defines our mobility architecture. Section 3 presents the routing protocol used to exemplify our solution. Section 4 describes the proposed solution. Section 5 reports the implementation steps and obtained results. Section 6 presents related work and Section 7 concludes this paper.

2. Mobility in Wireless Mesh Networks

Mobility in Wireless Mesh Networks (WMN) occurs whenever a client associated to an access point wants to change its point of attachment. For the communication with other correspondent terminals to be maintained, the terminal needs to constantly inform others about its current location. Any mobility solution in these networks must be able to quickly update the terminals location information with low overhead, to maintain a reliable, non-interrupted communication between nodes. Mobility can be performed in two different ways: the WMT loses its current WMR and changes to a new one; or it is able to announce that it is moving while having both WMR available. The first approach is traditionally denoted as reactive handover while the second one is a proactive handover.

In the reactive approach, when a terminal connects to a new WMR, it is this WMR that will have to announce the new location of the WMT. Typically, during a communication, handover information will be sent in the transport sub-network with the goal of reaching route convergence to the new location of the WMT.

In the proactive approach, the WMT informs its actual WMR that it will hand-over to a new location. While the WMT agrees the association with the new WMR, the old WMR informs the network of the change in the topology. This type of operation is more complex than the reactive one, but reduces largely the number of dropped packets and the time that the handover operation takes to be fully completed. Using additional mechanisms, such as back-tracing and caches, the packet drops can be significantly reduced, increasing the efficiency of the network and overall user experience.

The time it takes for the handover process to complete varies with the technologies used. Cellular technologies, such as the ones used in current GSM and UMTS networks, are able to support seamless connectivity between neighbour points of attachment. Wireless mesh networks, typically using 802.11, are usually not able to meet the requirements for voice continuity. Mail and Instant Messaging applications are not that affected by the mobility process, as long as it lasts for less than 1 or 2 seconds. VoIP applications are less tolerant, requiring handover durations below 100ms. Above this threshold, the perceived quality of service will drop, thus limiting the usage of this type of applications.

3. DSDV

Destination-Sequenced Distance Vector [2] is a multi-hop distance vector routing protocol (DSDV) for ad-hoc networks. The idea behind ad-hoc networks is to create self-organizing multi-hop wireless networks, without requiring infrastructures. While only a set of mobile nodes is capable of communicating directly with each other, it is possible to communicate by relaying messages to nodes in the neighbourhood and trying to create a multi-hop path from source to destination nodes.

This routing protocol uses the Distributed Bellman-Ford algorithm to determine the routes between the nodes. Each route has a sequence number determined by the destination, being each node responsible for managing its own sequence number. The sequence number indicates how old the route is. A higher sequence number indicates a new route, originated from a topology change. Then, when a *Route Update* message with a higher sequence number is received, the old route is replaced. If there is a conflict between two sequence numbers for different routes, other metrics are used to choose the best route. In order to save bandwidth, DSDV is able to perform an incremental update when routing updates occurs. These updates happens either periodically or when any significant topology change is detected. An incremental update only sends entries that have changed since last update. In opposite, a full update sends the entire routing table. Fluctuations in route updates are avoided recurring to a settling time data employed by the protocol, predicting the time when the route becomes stable.

DSDV brings great advantages as a routing protocol. It provides loop-free routes at all instants; even though it has a relatively high convergence time. Although this protocol was designed for ad-hoc scenarios, it suits the requirements of WMN and can also be used in these environments. Example of it is the MeshDV [4] testbed, which uses a modified version of DSDV in the fringe routers and un-modified DSDV on the other nodes (WMR).

4. Back-tracing Extension

Back-tracing is an extension that can be used in proactive ad-hoc routing protocols, with minor changes to the original protocol and without changes to the IEE 802.11 MAC protocol, to decrease the traffic disruption during handover. Following the objectives of WMNs, this extension aims at being completely transparent to the clients connected to the network.

This extension adds a new feature to DSDV protocol in what concerns to mobility management (Figure 1). In the original DSDV routing protocol, when a link is broken, any link through that path is immediately assigned an infinitive metric and the sequence number is generated by any node other than the destination one, so invalid route information will be transmitted through the entire network as new information, being heard by the nodes, except the destination one. When this information is recorded in nodes' routing tables, the nodes will wait for the next route update originated by the destination to rebuild its route to destination. In this interval, that can be very long (in the order of several seconds), a large set of routing packets will be generated and data packets will be dropped.

Back-tracing technique enables the re-forwarding of data packets when a handover occurs: when a link is broken, another one is immediately setup, connected to a different WMR. For this purpose, when the WMT is about to move, it sends a handover advertisement packet to its WMR with information of the new location. In this way intermediate nodes, between the source node and destination node, will sequentially re-forward the packets through the new location of the mobile terminal. Sequentially means that the handover advertisement will be sent only to the neighbours; only the ones who have data packets to the destination node will re-send them and re-forward the data packets according to the next hop in their routing tables towards the destination. This process will converge to the new route between the source and the new location of the destination node, using the intermediate routes to forward the data packets that were being sent during the movement of the node, minimizing the packets dropped during the mobility process.

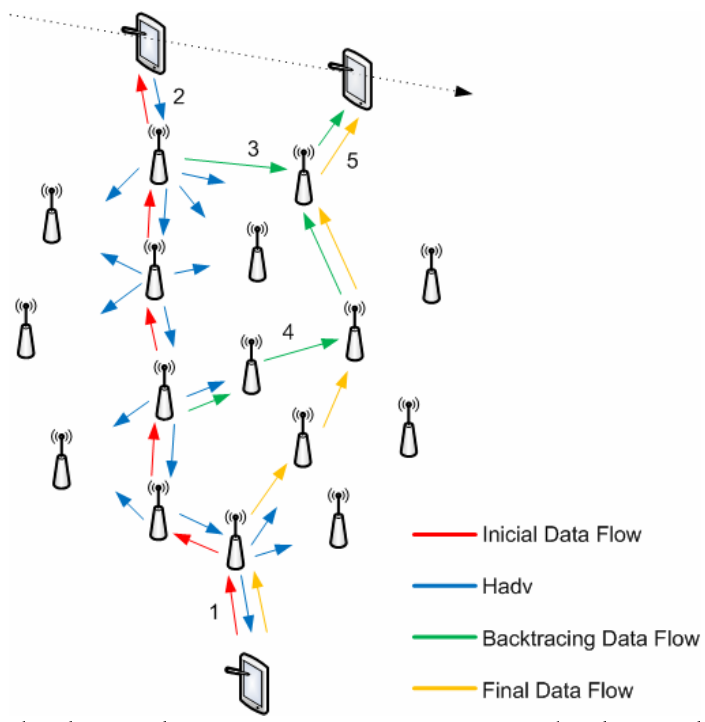


Figure 1. Steps between handover and route convergence, using proactive handover and back-tracing

In Figure 1 is depicted a handover process and the functioning of the back-tracing extension. The arrows with different colours represent the various steps of the back-tracing mechanism, supported in the numbers presented in the figure. In step 1, data packets are being transmitted from the correspondent terminal to the mobile one, using the wireless mesh network created by the WMRs. The route that has been chosen is the best one calculated by DSDV. This step is maintained unless mobility happens. When the WMT moves, it advertises its WMR and step 2 initiates. This step represents the handover advertisement that is broadcasted to WMRs. Only WMRs with active flows to this terminal continue the broadcast of handover advertisements until it reaches the source terminal. Meanwhile, step 3 and then step 4 occur. These two steps represent the re-route of data packets in transit. As WMR receives the information of the new location of the WMT, they update their routing tables and can re-route the data packets that were in transit to new location, calculating the route once again by DSDV. It should be noticed that re-route will occur until a WMR, common to old and new routes is found. In most situations, due to the topology of a WMN, the re-route will only affect one or two WMRs. In fact, the scenario depicted in Figure 1 describes a quite unusual scenario corresponding to a situation more complex than will be usually found. After a WMR receives a handover advertisement, it updates the location of the mobile terminal. At this time, it is capable to re-route data packets to the new location of the terminal. As DSDV is being used, the new routes are selected based on the DSDV routing protocol. Finally, step 5 represents the optimized route between the two terminals after the handover and the back-tracing operation.

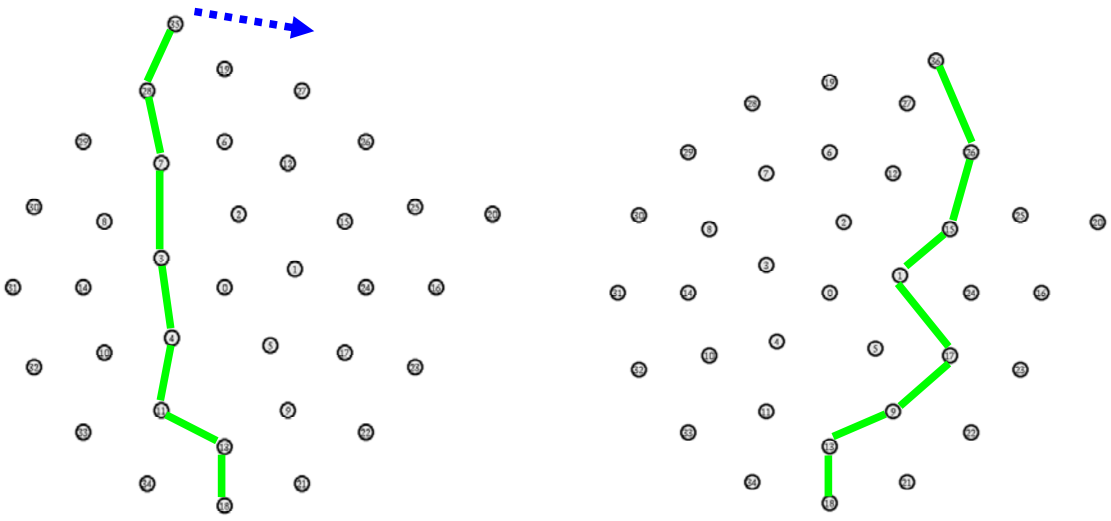
This type of process adds some complexity to the routing mechanism and assumes that existing technology is able to provide multiple attachment points for the terminals. If this support is not available, back-tracing mechanisms are also useful, but some flow interruption will be expected. However, we envision (and this is actually verified) that the disconnection time still allows the support of VoIP services without degradation.

While DSDV is used in this work, in terms of the solution presented, it should be considered as illustrative only. To our knowledge, the solution also applies to other pro-active routing solutions. In fact the work proposed was evaluated with other routing protocols such as OLSR or AODV. While AODV clearly demonstrated its inadequacy due to its reactive nature, OLSR presented results similar to the ones obtained with DSR. For the sake of brevity we decided to focus in a single routing protocol. Moreover the focus of this work is not the comparison of routing solutions but to describe and evaluate the effectiveness of our extension for pro-active routing protocols.

5. Simulations results

We performed simulations using the NS-2 simulator [5], in its version 2.31. The computer hosts were running Ubuntu Linux 7.10 with gcc 4.1.3 and kernel 2.6.22. Simulations were based on a network formed by 37 nodes, distributed in a cloud-type scenario, in a rectangular (500m x 500m) flat area. The IEE 802.11 MAC protocol, with a channel bandwidth of 11 Mbps, was used as the MAC layer protocol. The transmission range of each node was approximately 150m. Each simulation was run for 250 seconds.

Random-Waypoint was disabled as mobility model. In this model, each node is stationary, having only one mobile node that changes location at *t=143.0* seconds. Traffic source was UDP Constant Bit Rate (CBR) with packets of 84 bytes each. The sending rate was fixed at 100 packets per second and there is only one node generating packets. The communication is started at 0.0 seconds. As the handover is only preformed when *t=143* seconds, the network is considered to be in a stable state with no more route updates taking place. In order to better mimic the real world, an artificial 80ms delay has been introduced in the WMN. This delay is used to mimic the delay required for the network interface to change channel, as well as the network stack to configure a new address. The value is derived from previous work preformed and, for the sake of brevity, is out of scope for this paper. All other values, both for NS-2 and other protocols used are set to its default values. This scenario is depicted in Figure 2.



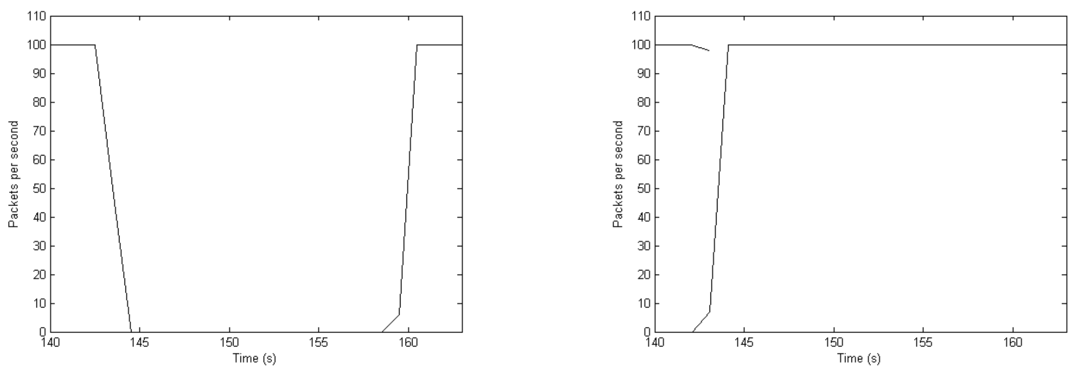
a): First route used, and direction of movement *b): Optimal route used after handover*

Figure 2. Scenario used in the simulations.

With this simulation environment, we evaluate DSDV with and without the back-tracing extension in the following metrics: throughput, jitter, packet loss and control overhead.

A. Throughput

As depicted in Figure 3, the results obtained during the handover process, with and without back-tracing extension, are quite different. In non-mobility situations throughput is stable. There is only one change during the handover execution. In the case of DSDV without back-tracing extension, the disconnection time is about 17 seconds. Such time corresponds to the time required for the network to converge upon a topology change. In the meantime all packets are dropped in the old WMR and in other WMRs that contain packets for this node, until the new location of the node is discovered by the routing protocol. In the case of DSDV with back-tracing extension, the disconnection time is only 80 milliseconds (the artificial delay). During this time, packets in transit are re-routed to the new location after handover advertisement travels through the intermediate nodes until they reach the source node. The time that it takes to inform the source node of the new location is, in this case, 32 milliseconds. During this time there are no data packets dropped, being successfully re-routed to the new location. After that, packets will go directly to the new location as the destination address corresponds to the new address of the WMN.



a): DSDV without using back-tracing extension. *b): DSDV Using back-tracing extension.*

Figure 3. Throughput without and with back-tracing.

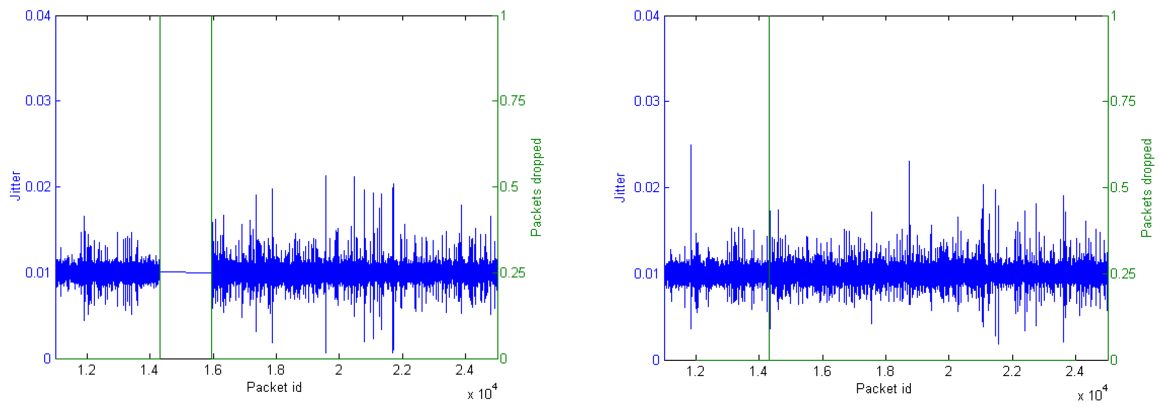
B. Jitter

Figure 4 shows both jitter and dropped packets. In DSDV without back-tracing there are visible changes in jitter, in particular during the handover time. In this time jitter is constant, since the packets are all being dropped and not being received in the destination node. After handover occurs, jitter becomes more unstable due to the changes in routes related with the use of DSDV as routing protocol. Using back-tracing extension there are no visible changes in jitter. The long steady time disappears and only some minor variations are noticed, due also to route changes and packet collisions.

C. Packets drop and Control Messages

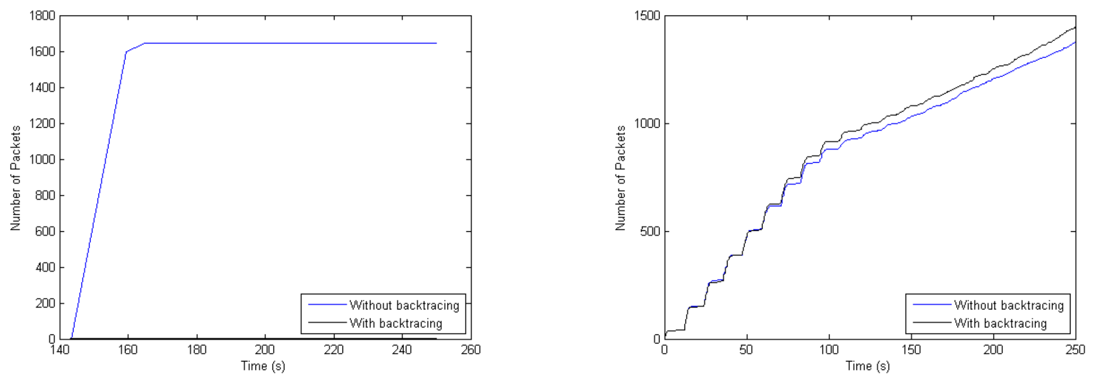
During the handover period, intermediate nodes do not know the new location of the mobile terminal until the *Route Update* messages are propagated and DSDV converges. All packets sent to the previous location will be dropped. As depicted in Figure 5 a), there are several packets dropped using DSDV without back-tracing (1645 packets). Such results are in accordance to the values presented previously related to throughput, jitter and losses during handover time. These packet drops occur at the intermediate WMR after the location of the WMT changes. In the case where back-tracing extension is used, only 2 packets are dropped. This corresponds to a drastic improve in terms of packet losses.

As wireless networks are resource constrained, it is vital to evaluate the effect of back-tracing in control overhead (Figure 5 b). With the handover advertisement messages added to the network, in particular during the handover time, the overhead will be slightly higher, with an increase of 5.09%. This is a small value of overhead, which is compensated by the drastic reduction on disconnection time and packets drops.



a): DSDV without using back-tracing extension. *b): DSDV using back-tracing extension.*

Figure 4. Jitter without and with back-tracing.



a): Sum of packet drop after network stabilization *b): Sum of control messages in the network*

Figure 5. Packet losses and overhead.

6. Related Work

There are several network-layer mobility management schemes. But most of them are not feasible to support fast terminal mobility in wireless mesh networks.

Mobile IP and Mobile IPv6 [6] are the IP mobility management schemes standardized by IETF [7]. In these schemes nodes play different roles such as: Home Agent (HA), Foreign Agent (FA), Mobile Hosts (MH) and

Communication Peer (CP). MH are the usual terminals, that are associated to a FA, and consequently, each FA is associated to a HA. HA is the central point, which forwards data packets for the mobile host and its communication peer, and keeps the function of location server, mapping the mobile host's home address. In this process the identity is mapped to its location, using the care-of-address of the mobile host. Mobile IP, as other schemes, requires network operators, mobile users and communication peers to upgrade their software to enable mobility support. Other problem is the large handover delay that Mobile IP incurs. All these requirements and problems are not feasible with wireless mesh networks concept. The mobility process requires communication between the FA and the HA, which translates in larger handover delays when the mobile host is far away from the HA. Testbed tests using Mobile IP in wireless mesh networks topologies show that the network-layer handover latency is about 600ms, 4 times larger than the value required to support uninterrupted real-time applications.

HAWAII [8] is a micro-mobility management solution. A Gateway Foreign Agent (GFA) is introduced in each domain, managing the Foreign Agents. This way, global triggers to the HA are reduced, withdrawing the macro-mobility management aspect that Mobile IP has. These design choices continues to involve the mobile hosts in mesh backbone routing and implement host-specific routing protocols. Even solving the large handover latency problem of Mobile IP, the improvements are not suitable for VoIP continuity in wireless mesh networks. The deployment of HAWAII suffers the same problems as Mobile IP: it is complex and does not explore the self-organization characteristics of wireless mesh networks.

SMesh [9] is fully based in wireless mesh networks. This scheme offers seamless handover system to a transparent wireless mesh system, supporting various kinds of real-time applications. One of the main characteristics of this network is the use of unmodified WiFi interfaces on terminals. Terminals are supported by a group of access points, Client Data Group (CDG), creating the WiFi backbone. Tests in SMesh present good results in handovers, with handover latency time approximate zero (ignoring hardware latency). Using the access points, during a handover, the traffic to the mobile host is sent by the access points using multicast. The usage of multicast of data packets consumes bandwidth, which normally will reach high values. Other issue is that as mobile hosts have capacity to communicate with multiple access points simultaneously, all access points must operate in the same channel. This way, access points loose the capacity of using other channels to increase access capacity of the wireless mesh network.

MeshDV approaches the problem of managing the network by having two sub-networks coexisting in the same wireless mesh network: the access sub-network, composed by the terminals, and the transport sub-network composed by the WMR. These two sub-networks contain the operation of different mechanisms. Highly adaptable routing solutions are required in the transport sub-network enabling WMR to route traffic from and to terminals. Terminals only need to maintain information about their points of attachment to the network. Traffic is sent towards the associated WMR and no routing protocol is required to be installed on the terminals. Standard versions of MeshDV use an approach of self-detection (a predictive approach) where a mobility manager module is responsible for managing the handover process. While being a valid approach, it has poor performance in MeshDVNet [4]. This is more noticeable with active communication, since while the association of a client with a new WMR is a fast process, forwarding packets will still be delivered to the old location for some time. The result is high loss during the handover period.

Enhanced Mobility Management (EMM) [10] is a new approach to MeshDV, improving mobility management. With this solution, a reactive approach for mobility management is implemented, where the new WMR performs the detection of the clients during their movement. This solves the delay refresh problem of the Neighbour Discovery Protocol (NDP) cache. Results show that EMM reduces the handover latency time in MeshDVNet. In some cases disconnection time was reduced from 3 minutes to only a few seconds; in some cases, it was reduced to values less than one second. Even being a valid and important improvement, it still cannot support real-time communication during the handover process.

7. Conclusions

The support for VoIP applications in current or future Wireless Mesh Networks is considered to be vital to its success. However, the wireless medium and routing protocols are frequently unable to meet the requirements for seamless terminal handover, while maintaining uninterrupted calls.

In this paper we propose a novel extension scheme to improve the mobility process during active data communication. It aims at improving the packet delivery ratio and reducing the disconnection time obtained when using proactive routing protocols. We illustrate its functioning using DSDV, but almost any pro-active routing protocol can benefit from this solution. Results obtained with NS-2 prove the efficiency of the solution and its effectiveness in meeting the real-time requirements of the communications.

Acknowledgments

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8. References

[1] F. Rosseau, Y. Grunenberger, V. Untz, E. Schiller, P. Starzetz, F. Theoleyre, M. Heusse, O. Alphand and A. Duda, "An Architecture for Seamless Mobility in Spontaneous Wireless Mesh Networks". *in Proc. MobiArch'07, Kyoto, Japan*, August 2007.

[2] C.E. Perkins and P. Bhagwat, "Highly Dynamic destination-sequenced distance vector routing (DSDV) for mobile computers." *in Proc. ACM SIGCOMM 94, London, UK*, Oct. 1994, pp. 234-244.

[3] IST WIP – An All Wireless Mobile Network Architecture, http://www.ist-wip.org.

[4] L. Iannone and S. Fdida, "Meshdv: A distance vector mobility-tolerant routing protocol for wireless mesh networks", *IEEE ICPS Workshop on Multi-hop Ad hoc Networks: from theory to reality (RealMAN'06)*, July 2005.

[5] The NS Manual (Oct. 2, 2006), http://www.isi.edu/nsnam/ns.

[6] C. Perkins, IP Mobility Support, *IETF RFC 2002*, October 1996.

[7] D. Johnson. C. Perkins, *et al.*, Mobility Support in IPv6, *IETF RFC 3775*, June 2004.

[8] R. Ramjee, T. La Porta, S. Thuel, K. Varadhan and S. Wang, HAWAII: A Domain-based Approach for Supporting Mobility in Wide-Area Wireless Networks, *In Proc. of ICNP'99*, November 1999.

[9] Y. Amir, C. Danilov, *et al.,* Fast Handoff for Seamless Wireless Mesh Networks, *In Proc. of MobiSys'06*, June 2006.

[10] M. Bezahaf, L. Iannone and S. Fdida, "Enhanced Mobility Management in Wireless Mesh Networks".