FastM in WMN: a Fast Mobility Support extension for Wireless Mesh Networks

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Abstract

In this paper we present a new extension to proactive routing protocols using a fast mobility extension, FastM, with the purpose of increasing handover performance in Wireless Mesh Networks. With this new extension a new concept is created to integrate information between neighbor wireless mesh routers, managing locations of clients associated to wireless mesh routers in a certain neighborhood, and avoiding packet loss during handover. The proposed mobility protocol is able to optimize the handover process without imposing any modifications to the current IEE 802.11 MAC protocol and use unmodified clients. Results show the improved efficiency of the proposed scheme: metrics such as disconnection time, throughput, packet loss and control overhead are largely improved when compared to previous approaches.

1. Introduction

Wireless Mesh Networks (WMN) [1] are dynamically self-organized and self-configured. WMNs increase the capabilities of ad-hoc networks, such as robustness, power management, reliable service coverage and optimized node mobility. 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). WMR are devices able to provide multi-hop transport mechanisms enabling communication between the terminals in the same or in different WMN. A terminal can be any type of device with a wireless interface (typically 802.11a/b/g), whether mobile or stationary. In the particular case of the WIP project [2], where this work was performed, terminals will mostly be comprised of laptops, desktop computers or PDAs, all supporting 802.11a/b/g.

In WMN, terminal mobility occurs whenever a client associated to an access point (or WMR directly) wants to change its point of attachment. To maintain communication with other terminals, the mobile terminal needs to constantly inform active correspondent nodes about its current location. Any mobility solution designed to these networks must be able to quickly update terminals location information with low overhead yet effectively, creating a reliable, non-interrupted communication between nodes. 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 unable to meet the requirements for voice continuity without further solutions.

In this paper we propose a new mobility mechanism for WMN denoted as FastM, Fast Mobility support extension for WMNs, an evolution of Enhanced Mobility Management (EMM) [11] and MeshDV [7], inheriting the basic functional aspects, but using neighboring tables and improved handover signaling process to avoid packet loss for the duration of the handover process, reduce control multicast packets in the network, save bandwidth and optimize the association and disassociation processes of clients to WMRs. The result is a much optimized and effective solution, able to provide voice continuity over WMNs.

The paper is organized as follows. Section 2 presents some of the most relevant mobility mechanisms in WMN in the literature. Section 3 introduces the basic routing and mobility mechanism that will be the basis for the protocol enhancements. Section 4 describes the enhanced mobility mechanism, FastM, our proposal for improved mobility in WMN. Finally, section 5 depicts the simulation scenario and the obtained results, and section 6 concludes this paper and describes the future steps.

2. Related work

There are already many mobility mechanisms for WMNs in the literature. In this section we describe some of the most relevant mechanisms, stating their benefits and drawbacks.

Ant [3] is a network-based local mobility management scheme for WMNs. Ant introduces some techniques to optimize handovers, such as: a) using the MAC-layer association event as signalling messages, b) maintain IP address of terminals unchanged while moving inside the WMN, and c) pre-establishing tunnels between neighbouring WMRs, supporting a list of WMRs neighbours created in each WMR. However, Ant presents some problems: a) the IP address of terminals does not reflect the topology, b) pre-tunnels must be available between every WMR neighbours, which introduces a

978-0-7695-3667-5/09 $25.00 © 2009 IEEE
DOI 10.1109/MESH.2009.23

scaling problem, and c) there is a centralized location server, managing all the location information of the network. In a small scenario with only 4 nodes, handover timing results in the order of 44.5 milliseconds are obtained [3].

MAMP [4] (Mobility-Aware Multi-Path) is a new scheme that uses the interconnection between Serving Access Points (SAP) and is supported on the existence of a Gateway. It is a multi-path mechanism for packet forwarding, creating a large number of connections between every node, with multiple alternative routes. In this scheme, when a mobile host registers in the network, a message will be forwarded from the correspondent SAP to the gateway, creating routing paths in every SAP that receives the message to the mobile host. Meanwhile, each SAP broadcasts to its neighbours the appearance of a new mobile terminal, and, recursively multi-path routes are created. This solution presents good performance, reducing handoffs delay comparing to other techniques, but needs SAP to have large capacity to deal in a large number of routes. Being this a proactive mobility protocol, it also gives the mobile host the responsibility to trigger the mobility process in the network.

MobiMESH [5] is a WMN mechanism where the network is organized in two sections (backhaul and access), each with a separate IP addressing space. MobiMESH uses a cross-layer mechanism associating MAC and IP layers, making possible to correctly announce associated clients on the backbone routing in a lightweight and fast manner. Results show that, in average, handover using MobiMESH takes 100ms. However, the association of MAC and IP layers may cause address conflict, and a complete conflict-free strategy may require a central location server or complex interaction between mesh routers.

SMesh [6] uses unmodified WiFi interfaces on terminals. Connectivity and transport is provided by a group of access points, creating the WiFi backbone. Results achieved with SMesh present good performance, with a handover latency time approximately equal to zero (ignoring hardware latency). The main feature contributing to these results in SMesh is the fact that during a handover, traffic to the mobile host is sent by the access points using multicast. However, multicast will consume additional bandwidth. Moreover, in 802.11, multicast data rates are lower than unicast. Other issue is that in order for a mobile terminal to communicate with multiple access points simultaneously, all access points must operate in the same channel. This last aspect will seriously reduce network capacity and inhibits the operation in some areas of the network due to high local interference from other radio equipments.

3. MeshDV and EMM

In this section we present two mobility mechanisms in larger detail, MeshDV [7] and Enhanced Mobility Management (EMM) [11], as they will be the basis of our proposal, FastM.

MeshDV is a solution proposed for WMNs based on equipments composed by two wireless interfaces, each dedicated to a different sub-network: one offering connectivity to end-user terminals; the other forming a self-organized wireless backbone. The *client* interface is configured as an access point, while the interface used to maintain the wireless backbone, the *mesh* interface, is configured in ad-hoc mode. These two sub-networks will have different routing and addressing mechanisms operating on them. Highly adaptable routing solutions are required in the transport sub-network enabling WMR to route traffic from and to terminals. For this task, it was proposed a routing solution based on the DSDV routing protocol [8] running in IPv6 [9]. Clients only need to maintain information about their current point of attachment to the network. Traffic is sent towards each correspondent WMR and no modification to the routing protocol is required at the terminals.

Each WMR has a Local and a Foreign Client tables (LC and FC) that keep track of clients present in the network: the LC table contains the list of clients directly assigned to the WMR; the FC table contains the information about clients and their correspondent WMR, which is required in order to allow communication between these nodes and the local ones. MeshDV uses a tunnel-based approach creating a communication channel between end terminals. Terminals only need to know the IP address of the destination client and query the current WMR (using ARP or IPv6 Neighbor Discovery mechanisms). When the client queries the WMR for the location of a given node, the WMR will search its LC table. If the node is not local, it then queries other WMRs in the network and adds this information to the FC table. The client only needs to send packets to its correspondent WMR. The WMR will then create a tunnel for the communication with the correspondent WMR of the destination client.

The module making all this process transparent makes use of the Neighbor Discovery Protocol (NDP) [10], which is ubiquitous in all systems. This way, clients do not need any additional mechanism to communicate, making possible the integration of off-the-shelf equipment without modifications. Traditionally, nodes use NDP to maintain track of the local neighbors and check their local reachability. NDP uses a set of packets and caches to share and maintain information related to nodes in a network. Using MeshDV, the protocol will alter the operation of NDP (at the WMR), allowing impersonation of the remote terminals.

MeshDV introduces several additional messages in order to manage communication, association, and disassociation events. These messages only exist in the backhaul part of the network and are mostly related to the discovery and advertisement of clients:

- MCREQ – Multicast Client REQuest – This type of message is sent by a WMR when the location of a client in the wireless mesh network is unknown.
- UCREQ – Unicast Client REQuest – This is a periodic message that is generated by the WMR to check if the information present in the FC table regarding a particular client is still valid. The purpose is to confirm if reachability still exists.
- CRREP – Client Request REPly – When a WMR receives a MCREQ or a UCREQ and if the client is connected (present and active in the LC table), the WMR answers with this type of message.
- CWIT – Client WIThdraw – When a client disassociates from a WMR, this message is sent to all the WMRs which requested information about this node, notifying for the state change. This way, the WMR that had an entry to the withdrawing client in its FC table can update the entry to reflect the changes in the topology.
- CWREP – Client Withdraw REPly – When a WMR receives a CWIT message and has an entry with the client address in the FC table, it sends a CWREP packet to the WMR that issued the CWIT announcing that the entry was deleted from the table.

In MeshDV mobility management is based on feedback from the wireless card (MAC layer) and periodic messages (IP Layer). The problem with this approach is that it is affected by the beacon timeout configuration of the wireless driver. When timeouts are considerably long, it is possible that (incorrect) information regarding some node is kept in a WMR for a long time, resulting in connectivity problems. WMRs, as defined by MeshDV, are responsible for all tasks of the handover process, communicating with the others WMRs in order to update caches and maintain information coherent. 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 the real world. This is more noticeable with active communications because while the association of a client with a new WMR is a fast process, packets will still be delivered to the old location for some time. The result is high packet loss during the handover period until caches expire (a few seconds). This process must be performed in a completely transparent manner to the terminals and consuming the minimum bandwidth. Also, handover must be a fast process with minimal packet loss, giving terminals the possibility of maintaining active communications across different attachment points.

Enhanced Mobility Management (EMM) [11] is a new optimization to MeshDV, designed to improve mobility management, and reduce handover delay. With this solution, a new reactive approach for mobility management is proposed, with the detection of the clients during their movement performed by the new WMR. This solves the refresh delay problem created by the NDP cache [10]. Results show that EMM [11] reduces the handover latency time in MeshDVNet, in some cases from 3 minutes to only a few seconds or less than one second. The main change that EMM adds to MeshDV is a new type of message that is sent when a client changes its WMR association. EMM also proposes modifications to some of the original messages and mechanisms first proposed in MeshDV. Figure 1 depicts de EMM message sequence diagram of a handover process.

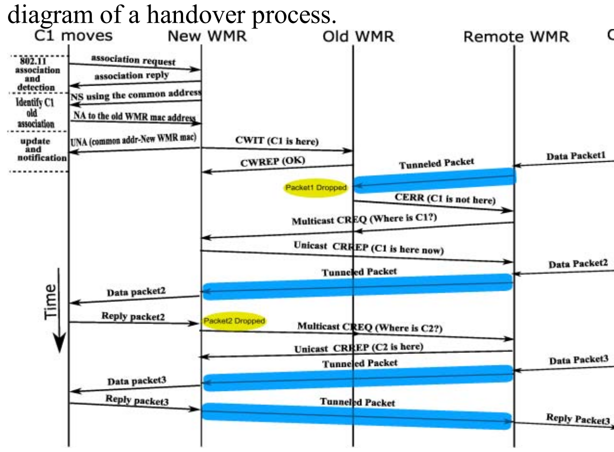

Figure 1. Communication diagram of EMM

One of the messages added is the Unsolicited Neighbor Advertisement (UNA), which is sent by a node to inform its neighbors that its link-layer address has changed, correctly updating the NDP cache of its neighbors with the MAC address of the new WMR. EMM adds an important feature to WMRs: when movement occurs, the old and the new WMRs exchange information related with the old association of the client. This way, the new WMR will receive from the clients the address of the WMR where they were associated (via NDP) and update with its own address (UNA message). Meanwhile, the new WMR informs the old WMR of the association context related to a client. Also, the old WMR will be instantly notified about the new location of its former client and clean local caches.

When a WMR receives traffic from one of its clients with a destination MAC address different than its MAC address, the packet is not discarded. Instead, the packet is tunneled and forwarded to the proper WMR serving the destination address. Then, the WMR sends an UNA message to the client in order to update its NDP cache with the value corresponding to the MAC address of the WMR.

Other message that is added to the MeshDV system is the Client Error message (CERR), which is sent by the

destination WMR directly to the source WMR, informing that the client is not associated with it anymore. Receiving a data packet to a node that was removed from the LC table triggers this message.
EMM corrects most of the issues affecting the original MeshDV proposal aiming to be adaptable to wireless mesh networks in general. Results in [11] show reduced disconnection times by a large factor. However, EMM still achieves results in the order of seconds, thus it is unable to support voice continuity in wireless mesh networks. The problem is that data packets in transit during the mobility process are dropped by the WMR previously used by the client. Another issue is the existence of a large control overhead sent to the network when mobility occurs. Solutions to WMNs must simultaneously offer better performance in adapting to the actual requirements and be easy to deploy in real networks.

4. FastM: Fast Mobility Support extension

FastM was developed to further optimize mobility in WMNs. It is an evolution of EMM and MeshDV, inheriting the basic functional aspects, but modifying relevant aspects and adding a significant set of effective features. As MeshDV, FastM uses both LC and FC tables, and adds a new table named Neighbour Client (NC) table used to keep information about neighbour nodes. With the addition of this table, a new set of control messages is used in order to maintain the coherence of the mesh network. These changes aim to avoid packet loss for the duration of the handover process, reduce control multicast packets in the network, save bandwidth and optimize the association and disassociation processes of clients to WMRs. The result is a much optimized and effective solution providing voice continuity over WMNs.
With the NC table, all updates made to the LC and FC tables in any WMR are broadcasted to all its neighbors. This produces extremely less Clients Request packets and speeds the handover process. Updates to the NC tables are made when a mobility process triggers changes to LC and FC tables of a neighbor WMR. From real experiments we notice that handovers are typically performed to neighbor WMRs. In this case, when a data packet reaches an old WMR, the address will be found in the NC table and the WMR automatically re-tunnels the packet towards the new location of the client, avoiding packet loss.
FastM uses a new set of messages to improve the mobility process:
- CLIENT_IS_THERE – When a WMR receives data packets to a client that is in its NC table, the WMR checks its FC table and a message is sent to the WMRs that had communication with that client containing the new location of the client. This mechanism gives FastM the capacity to also support mobility that involves other WMRs besides the direct neighbors.
- CLIENT_IS_THERE_CONF – After receiving a CLIENT_IS_THERE message, the WMR sends to the new correspondent WMR of the client that moved, information about the location of a client that was involved in the communication process. This message acts as a confirmation to the handover process.
- TABLE_UPDATE – This message is broadcasted to neighbors (TTL=1) when an update on a WMR Client table is made. Updates like associations, disassociations, and handovers are then known by every WMR in the neighborhood.
- TABLE_UPDATE_HELLO – In order to periodically check node reachability status, WMRs send a TABLE_UPDATE_HELLO message every 30 seconds, announcing that they are still connected to the network and that no changes had occurred.

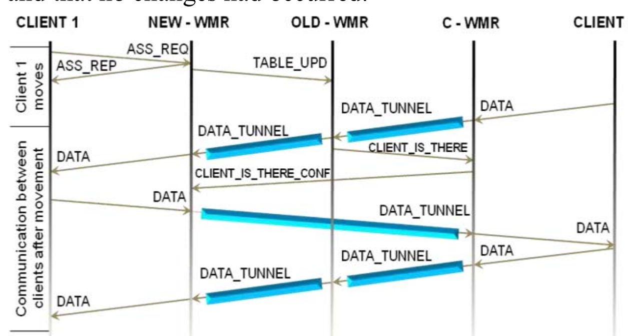

Figure 2. Communication diagram of FastM

Figure 2 depicts the communication diagram of a handover. The changes that characterize this procedure are immediately noticed: there is a tunnel between old and new WMRs to avoid the existence of dropped packets, and no multicast packets are sent to locate clients in the network. FastM uses the ability of sharing information related to local and foreign clients by the WMRs.
As can be shown in Figure 2, there are some essential steps in FastM mechanism:
1) Client 1 issues an ASSOCIATION_REQUEST message to a new WMR. This is a standard 802.11 message.
2) The new WMR accepts the association with an ASSOCIATION_REPLY message sent to Client 1 and broadcasts a TABLE_UPDATE message to all neighbors WMR informing the changes in the topology.
3) When data packets depart from the correspondent WMR of Client 2, the destination is the old WMR, because the new location is unknown both to Client 2 and to its WMR. Data packets arrive to the old WMR and are re-tunneled to the new WMR. Meanwhile, the old WMR sends a CLIENT_IS_THERE message to the correspondent WMR with information about the new location of Client 1.

4) Correspondent WMR answers to the new WMR with a CLIENT_IS_THERE_CONF message, confirming the knowledge of the new location and informing the new WMR with the location of clients that were communicating with the Client 1.

In the first step, the client sends an ASSOCIATION_REQUEST message. However, scanning delays is out of scope of our work. The problem of loosing performance with scanning delays can be resolved using solutions like the one described in [12].

Basically, these are the steps that FastM makes in order to complete a handover process. There are also changes in the Client Tables of WMR to process the messages exchange during the handover to predict future handovers and facilitate them, with the same premises of FastM.

5. Simulation results

The solution described above was implemented and tested using the NS-2 simulator, version 2.31 [13]. A cloud-type scenario has been chosen with 37 nodes, in a square flat area of 6400 m2 (800m x 800m). The MAC layer protocol is the IEE 802.11 with 11 Mbps of channel bandwidth, and 150m of transmission range of every node. The scenario is depicted in Figure 3.

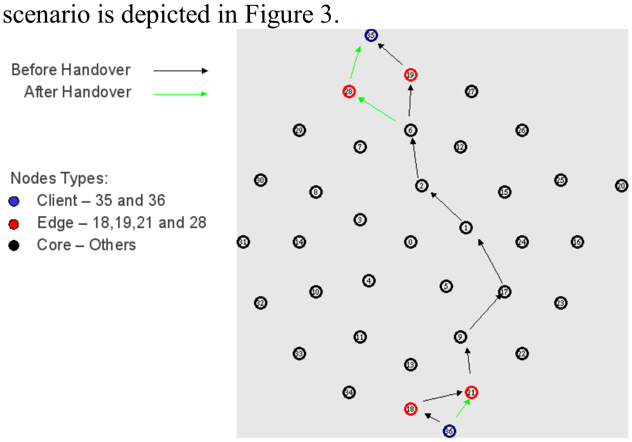

Figure 3. Simulations scenario

The characteristics of the scenario in the UDP and TCP simulations are shown in Table 1. In all simulations the receiver node performs handover at 270 sec, the sender handover is performed at 370 sec, and the simulation time is 450 sec.

Table1. Characteristics of the scenarios

	Configuration 1	**Configuration 2**
Traffic type	UDP CBR (constant)	TCP
Packets size	84 bytes	1060 bytes
Sending rate	100 pac/sec	N/A
Number of flows	1	1

In order to better mimic the real world, artificial delays have been introduced in the WMN. These delays are used to emulate the delay required for the network interface to change channel and the network stack to configure a new address (50 milliseconds). The value is derived from previous work performed [14]. Other relevant aspect is the artificial control delays implemented in NS-2 to approximate even more the simulations to real situations, in what refers to the implementation of MeshDV, both in EMM and FastM. All other values are set to their defaults.

Using this simulation environment, we evaluate MeshDV without and with FastM, according to the following metrics: throughput, packet loss and control overhead.

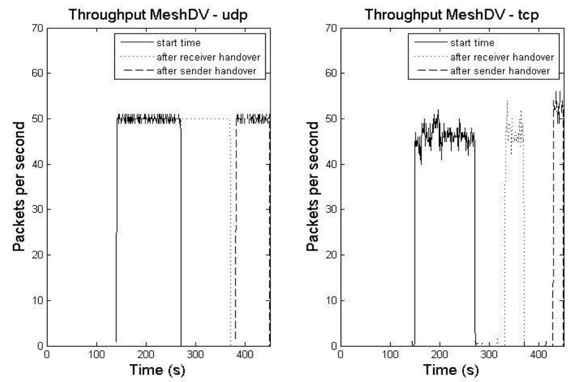

Figure 4. Throughput of MeshDV

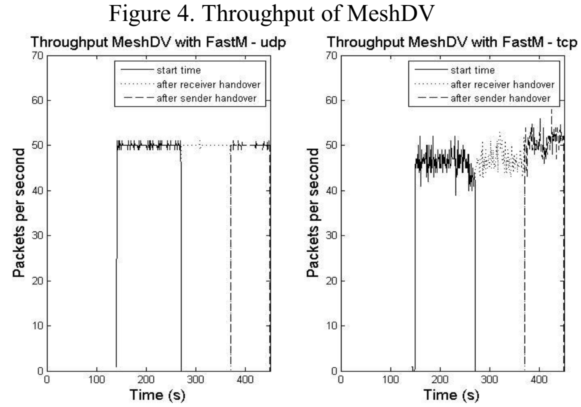

Figure 5. Throughtput of MeshDV with FastM

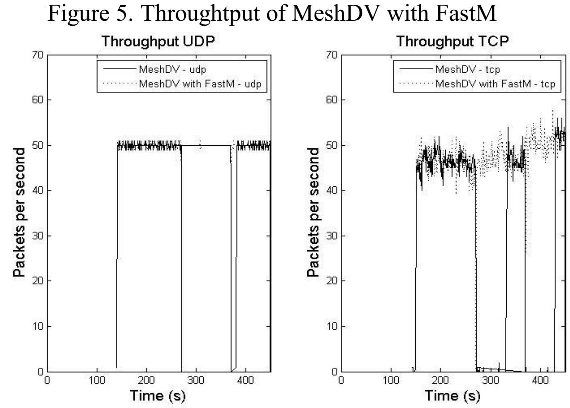

Figure 6. Comparison between throughput in MeshDV without and with FastM

A. Throughput

As depicted in Figure 4, 5 and 6, the results obtained during the handover process, without and with FastM extension, for both configurations, are quite different. In static situations throughput is stable, having some variations when mobility occurs in the scenario. Table 2 presents disconnection times in several experiments, comparing physical results, obtained with MeshDV and EMM in real testbed, with other results from simulations in NS-2. Comparing the disconnection times in Table 2, the values obtained in FastM are lower. With UDP traffic, even when sender and receiver clients move, traffic values are reduced and the timeout imposed by the wireless driver and NDP are overcome. Using TCP traffic the differences are more than evident: the techniques implemented in FastM are able to lower the disconnection time to milliseconds and maintain the throughput almost stable. The mechanism that supports re-tunneling of packets in transit is other important addition to maintain a stable throughput.

Table 2. Disconnection time comparison

	Receiver Handover (s)		**Sender Handover (s)**	
	UDP	**TCP**	**UDP**	**TCP**
MeshDV 1)	15	240	190	185
EMM 1)	2	40	4	35
NS2 MeshDV 2)	0.279	61.287	0.340	59.537
NS2 MeshDV 2) 3) 4)	0.279 + [0,180]	61.287 + [0,180] + [0.30]	0.340 + [0,180] + [0.30]	59.537 + [0,180] + [0.30]
NS2 FastM 2) 4)	0.118	0.344	0.089	0.141

1) Results obtained on a physical testbed
2) Results obtained through simulation
3) The wireless driver used in AP's have a delay between 0 and 180 seconds that can interfere in associations with different AP's
4) Due to the use of NDP in clients, there's a timeout between 0 and 30 seconds to update entries in active sessions

B. Dropped Packets

Figure 7 shows the dropped packets in every scenario. The results using FastM in MeshDV shows a large decrease of dropped packets during handovers, both in UDP and TCP traffic.

Using UDP traffic this is more noticeable due to a 10 seconds gap in which the communication between the clients is non existing due to NDP session timeout (being the handover at *t=370* seconds, it only needs 10 seconds to the NDP timeout, since it is issued every 30 seconds), period in which there is a large number of dropped packets as session in the server client is not updated to the new WMR. When the receiver handover takes place (*t=270* seconds), there is a small number of dropped packets, during the period that the WMR associates to the source client and needs to locate the receiver client.

With respect to FastM, there are no dropped packets when the receiver handovers to a new WMR. This is due to the re-tunnel of packets in transit. When the server handovers to a new WMR, there are packet losses during the time it disassociates and associates to a new WMR. A reduction of 97.3 % (546 to 15 packets) is obtained with the use of FastM in MeshDV. Using TCP traffic in the simulation, a reduction is also obtained, in this case of 35.1 % (57 to 31 packets). In this case, as it is shown in Figure 8, there are fewer packets generated when FastM is not used in MeshDV, which will also result in less packets being dropped. This is due to unknown locations of clients after handovers. With FastM there is always generation of packets and some drops exist due to some TCP characteristics, such as drop links and full queues, during the simulation period. During handover times, only 7 packets are dropped (4 in the first, 3 in the second handover) between the disassociation and association times of clients to a new WMR.

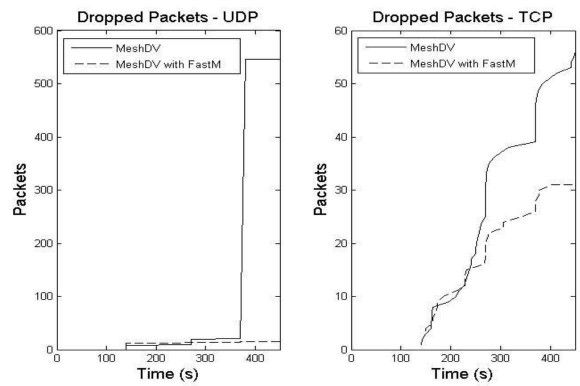

Figure 7. Sum of dropped packets after stabilization

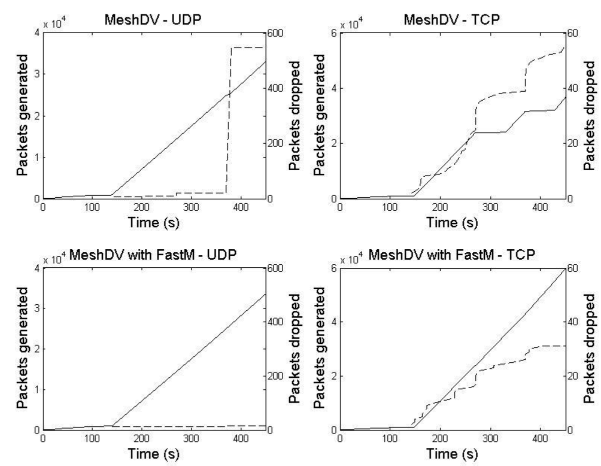

Figure 8. Comparison between generated and drops packets

C. Control Messages

In what refers to control messages (Figure 9), there are significant changes using MeshDV without and with FastM. Analyzing first the performance of MeshDV without the extension, we see a typical and coherent process during the simulation, using UDP or TCP traffic. The initial packets (*t=10* seconds) are due to the initial associations of the clients to the WMRs. At *t=140* seconds, when the transfer of data clients starts, control packets are generated to locate the clients in the WMN. With TCP traffic there are two client location processes (the second is at approximate *t=143* secs) because of the two-way traffic in TCP traffic. Then, in each handover, control packets need to be generated because of the new locations of clients. In TCP, due to the loss of links, some exchanges of packets are performed after the handover takes place, having disconnection time during that time.

Using FastM extension in MeshDV, when mobility takes place, control packets are reduced. Due to the existence of the NC table, there are TABLE_UPDATE_HELLO every 30 seconds (as can be seen in Figure 6). In the handovers, FastM reduces the control packets from 117 packets to 112 packets in UDP traffic, and from 226 packets to 152 packets in TCP traffic. In this type of traffic, a reduction of 32.7% in control packets is obtained with this extension. This will be even more significant in a scenario with a larger number of mobile nodes and handovers.

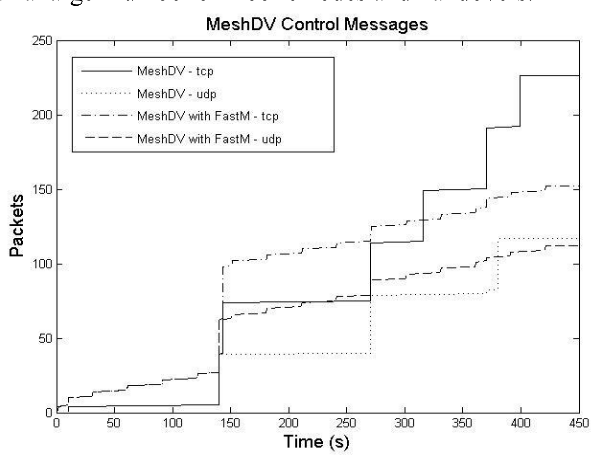

Figure 9. Sum of control messages in the network

6. Conclusions

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

In this paper we proposed a novel extension to improve the mobility process, denoted as FastM, that brings a new way to deal with neighbourhoods, using other nodes to maintain information about the organization of the WMN. Results obtained with NS-2 prove the efficiency of the solution and its effectiveness in meeting the requirements of low packet loss, disconnection times, and control overhead.

This solution was applied in this paper to MeshDV; however, its concepts are applicable to most proactive routing protocols. Future work in this area concerns the implementation of the mobility approach and the comparison of simulation and experimental results, to assess the behaviour of these mechanisms in real environments. Moreover, a comparison should be made with different mobility solutions.

Acknowledgments

This work was partially supported by the European Commission project IST-WIP under contract 27402.

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