Vertical Handover Decision Algorithm from WiMAX to WLAN based on the Mobile Node's Speed and the Session's Priority

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Abstract

The vertical handover decision strategy in the heterogeneous wireless networks is very challenging issue because it needs to deal with many different radio access networks and make decisions for vertical handover calls between them. Due to traffic offloading the decisions for vertical handovers to WLAN hotspots in heterogeneous wireless networks are very important because they impact the QoS of the mobile users, especially when they are using real-time services. In this paper we propose vertical handover decision algorithm from WiMAX to WLAN networks based on the user's speed and session's priority (non-real-time or real-time service) of the mobile nodes. We use the IEEE 802.21 standard as a layout for implementing the algorithm. The implementation of our handover algorithm avoids unnecessary vertical handover from WiMAX to WLAN in scenarios with various traffic types and speeds of the mobile nodes. The results show that the proposed algorithm improves the vertical handover latency, packet loss and average throughput of the mobile users.

Keywords: *Average throughput, Packet loss, Vertical handover latency, WiMAX, WLAN*

1. Introduction

The integration of various wireless technologies and the development of new mobile terminals equipped with multiple interfaces together with real-time and non-real-time applications has enabled the users to have seamless and continuous services anywhere in anytime [1]. The 4G standardization is already finished in 3GPP radio access with LTE advanced and in non-3GPP radio access with Mobile WiMAX 2.0 (IEEE 802.16m). As the concept of heterogeneous networks already began to implement as an idea in the 4G approach, it is for sure that in 5G approaches [2] the mobile users will also have an opportunity to access to different radio access technologies during their sessions without any interruption in the communication process.

A key role when the users switch from one network to another in this type of mixed wireless environment has the mobility management. One of the most important components of the mobility management is the handover management. It is responsible for changing the attachment of the mobile terminals while crossing from one wireless technology to another.

The vertical handover decision strategy is a key factor in the handover management of the heterogeneous wireless networks. The decision for vertical handover depends on many factors (cost, load, network bandwidth, coverage, security speed, power consumption etc.) that need to be considered together with the signal strength in the complex heterogeneous wireless environment.

There are many research papers that propose various vertical handover decision algorithms based on different aspects. In [3] the authors develop a vertical handover decision algorithm that enables wireless access network to balance the overall load among attachment points and maximize battery lifetime of mobile nodes. In [4] the authors propose a new user centric algorithm for vertical handovers, with a combination to continuously maintain the connection and to maximize the user throughput, implemented in existing standard technologies like 802.16 and 802.11.

When there is an option to make a vertical handover from WiMAX to WLAN, the vertical handover decision criteria are not the same as those in the vertical handover from WLAN to WiMAX. In this particular case, since WLAN has drastically lower coverage area than WiMAX, the mobile node can keep the connection to the WiMAX network while it moves into the WLAN coverage. None of the aforementioned and so far published contributions for vertical handover decision criteria in heterogeneous networks, including the IEEE 802.21 standard, have deeply researched the effect of the speed of the mobile users and session’s priority to decide upon vertical handover from WiMAX to WLAN networks. When the mobile node detects the WLAN network, and there is current real-time and non-real-time traffic between the mobile nodes and the base station of the WiMAX network, it is not needed to handover to the WLAN if there is ongoing real-time traffic between the mobile node and the base station. When the mobile nodes move with higher speed, there is no need to process the vertical handovers to small cells like a WLAN, because the user will be covered in a short time period [5]. Furthermore, the WLAN network is more sensitive to higher speeds of the mobile terminals comparing with WiMAX or LTE (UMTS), hence it is very important to consider the speed when deciding whether to trigger a vertical handover to WLAN network.

The above mentioned facts were our challenges to design a vertical handover decision algorithm that will decide upon the speed of the mobile terminal nodes and the priority of their sessions (high priority – real-time traffic or low priority – non-real-time traffic) whether to trigger or no vertical handovers when approaching the coverage of some WLAN network. A problem that arises in the practical implementation of this kind of algorithm is how to measure the speed of the mobile terminal. There are research papers that deal with this kind of problem. In [6] information for the mobile node’s speed can be detected from the Doppler spread in the received signal envelope. In [7] the traveling speed of the mobile terminal is measured by an accelerometer embedded in the mobile terminal.

Therefore in this paper we propose an algorithm that will be dependent upon the speed of the users and their session’s priority and will consider speed’s threshold and session’s priority regarding the vertical handover from WiMAX to WLAN network.

The structure of this paper is as follows. Section 2 explains the vertical handover process between WiMAX and WLAN in heterogeneous networks. Section 3 describes the proposed vertical handover decision algorithm. Then, Section 4 presents the results from the performance evaluation of the proposed solution. Finally, Section 5 concludes the paper.

2. Vertical Handover Process between WiMAX and WLAN

The vertical handovers are very important part in the field of heterogeneous networks. When a mobile node is moving between different technologies, like WiMAX and WLAN, the connection between different base stations also has to move. WiMAX and WLAN networks are complementing each other in terms of data rates, coverage area, QoS support, installation cost. In real life scenarios mobile users might prefer to perform vertical handovers from one wireless network to another based on various factors as quality, service cost, speed and availability. WLAN networks are cheap for installation and operation but they have limited coverage and minimal mobility support. WiMAX (Worldwide Interoperability for Microwave Access) offers wireless access in metropolitan area network. Vertical handovers are supported by the Mobile IP. Mobile IPv6 (Internet protocol version 6) is composed of three functional entities, MN (mobile node), HA (Home Agent) and FA (Foreign Agent). When a mobile node moves to a foreign network with different technology, COA (care-of-address) is acquired in order the mobile node to be uniquely identified in the foreign network. Home Agent of the mobile node registers this care-of-address in the home network of the mobile node. Then, the traffic is tunneled to the COA of the mobile node by the Home Agent.

The process of vertical handover must be seamless to the user. It depends on the type of traffic the user is requiring. If it is real-time traffic like VoIP or video, the mobile user can notice disruption in the session more easily than a mobile user that is browsing a website or transferring some files. Two essential factors for seamless vertical handover are vertical handover latency and packet loss. They must be as low as possible to make vertical handovers seamless, especially for mobile users that have real-time applications.

The order of events that occur between the mobile node and network in the process of vertical handover from WiMAX to WLAN coverage is explained in this section. We assume that a specific mobile node starts to move in a WiMAX cell and in its trajectory a WLAN network is detected. When this happens WLAN interface from the mobile node detects beacons from 802.11 and triggers the event “Link Detected”. MIH (Media Independent Handover) Agent that is in the mobile node is receiving this event and if it is better interface it gives command to the WLAN interface of the mobile node to connect to the WLAN access point.

In the next phase the WLAN interface from the mobile node and the WLAN access point exchange frames with events “Association Request” and “Response” in order to make a link between the mobile node and the WLAN cell. The WLAN interface triggers “Link Up” event after it receives the “Association Response”. This event is received from the MIH Agent in the mobile node and then it commands to the MIPv6 (Mobile Internet Protocol version 6) agent of the mobile node to request ND (Neighbor Discovery) Agent in order to send an RS (Router Solicitation).

The access point from the WLAN network receives the RS, so it detects that it is a new neighbor. It reacts on that with sending a RA (Router Advertisement) that includes the router lifetime, prefix valid lifetime, network prefix and advertisement interval. The WLAN interface of the mobile node receives the RA and reconfigures its address in dependence on the received prefix. The MIH Agent of the mobile node is notified about this.

The MIPv6 Agent from the mobile node gives command to the WLAN interface to send a “Redirect” message to the CN (Correspondent Node) for the purpose of informing the CN about the new location of the mobile node. The MIPv6 Agent of the CN receives then the “Redirect” message and sends after that an Ack (Acknowledge) message that is received by the WLAN interface of the mobile node. It then notifies the MIH Agent of the mobile node.

Now the MIH Agent from the mobile node has the confirmation that CN knows the new address of the mobile node and redirects the receiving of the traffic from the WiMAX interface to the WLAN interface. Hence, the traffic now uses the link between the WLAN interface from the mobile node and the AP.

The MIH Agent from the mobile node gives command to the WLAN interface to send a MIH Capability Request to the access point (AP). The MIH Capability Response is responded from the AP including the MIHF (Media Independent Handover Function) identification. Consequently, the MIH Capability Response is received from the MIH Agent with the identification of the new remote MIHF identification.

When the mobile node is approaching the boundary of the WLAN coverage the WLAN interface is triggering the event “Link Going Down” that is based on the received power of the beacon frames. When the probability that the WLAN link goes down gets a predefined value (usually 90%) and because the WiMAX interface of the mobile node is still active, MIPv6 Agent of the mobile node gives command to the WiMAX interface to send the message “Redirect” to the CN. In this way the CN is informed about the new location of the mobile node. The MIH Agent of the mobile node also gives a command to the WLAN interface to execute a “Link Scan” for searching another WLAN network.

If a “Probe Response” is received only in the channel where the mobile node is currently, MIH Agent from the mobile node is assured that this is the only accessible WLAN network. Then, the MIPv6 Agent of the CN receives the message “Redirect” and sends the message “Ack” that is received by the WiMAX interface of the mobile node. The MIH Agent is informed about this.

The MIH Agent of the mobile node has the confirmation that the CN is informed about the new address of the mobile node and is redirecting the reception of the traffic from the WLAN interface to the WiMAX interface. The traffic now uses the link from the WiMAX interface of the mobile node and the base station. In the same time the WLAN interface of the mobile node is triggering the event “Link Down”, hence the mobile node is disconnected from the WLAN network.

3. Proposed Algorithm for Vertical Handover Decisions from WiMAX to WLAN

Our proposed algorithm is aimed for vertical handovers from WiMAX to WLAN networks. It makes vertical handover decision from WiMAX to WLAN network considering the speed of the mobile node and the priority of the traffic class. It determines whether the incoming requests for vertical handovers from WiMAX to WLAN network will be rejected or accepted. If the speed of the mobile node while approaching the WLAN network from WiMAX network is above the acceptable threshold for the WLAN technology the incoming request for handover will be rejected and the mobile node will stay in the WiMAX network. If the speed of the mobile node is below the threshold and if the session’s bandwidth is lower than the WLAN bandwidth, the other criterion of the algorithm must be fulfilled to start the process of the vertical handover to WLAN. The other criterion for mobile nodes is the session’s priority. If the session’s priority is low, the vertical handover procedure will start. If the session’s priority is high, the mobile node will stay in the WiMAX network. The algorithm is implemented following these assumptions:

- The geometry of the WLAN cell is circular;
- The mobile terminals are moving across the coverage of WiMAX and WLAN cells with a constant speed and in a straight line.

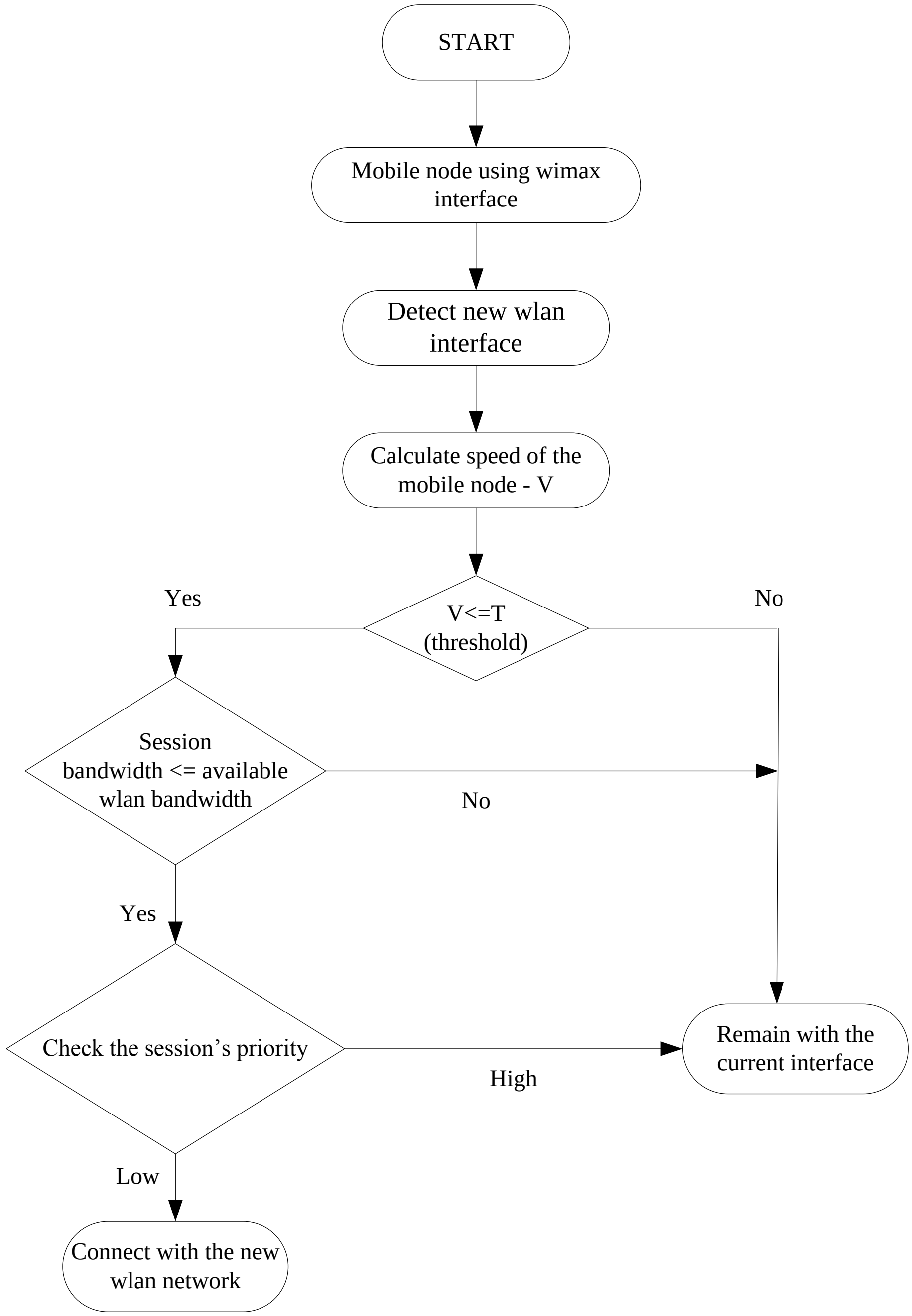

Figure 1. Proposed Vertical Handover Decision Algorithm

Applying the algorithm we achieve better channel utilization when using WiMAX/WLAN networks while still satisfying the QoS requirements of the users. It is applied only for the vertical handovers to the WLAN networks because the Access Points (AP) of the WLAN networks has lower coverage radius (from 50 to 100 meters depending on the type of 802.11 standards). When the radius of the AP is lower and the speed of the mobile node is higher it is better not to trigger a vertical handover to that AP. Furthermore, when there are mobile users with various types of traffic – real-time or non-real-time, it is better mobile users that use real-time traffic not to trigger vertical handover to the AP, because they are more sensitive to delays and handover latencies. Hence, we take this two important parameters, speed and priority of the session when deciding whether to make vertical handover to particular WLAN AP. The scheme of our proposed algorithm is shown in Figure 1. Let *V* be the speed and let *T* be the threshold speed of the mobile node terminal in Figure 1.

The mobile users that move with speed above the acceptable velocity threshold will not be allowed to perform handover to WLAN from WiMAX. Among the users that move with a speed under the threshold, the algorithm checks if the traffic priority is low or high. We consider real-time traffic as high priority session like conversational or streaming. Non-real-time traffic, like web or background is regarded as low priority session in the algorithm. Hence, if the priority of the used traffic is low, than the algorithm will allow a vertical handover to the WLAN network. Such vertical handover decision algorithm can be implemented in any proposed mobility management architecture for heterogeneous networks in 4G and 5G standards.

We have implemented and tested our designed algorithm in the IEEE 802.21 standard for Media Independent Handover (MIH) [8]. Simulations has been done using the handover module in the network simulator (ns) [9], and our added vertical handover decision algorithm in the module, explained in Figure 1. The IEEE 802.21 add-on module is based on the signal strength and the type of interface for the interface selection. Adding our developed algorithm we are enhancing the module with the information about the mobile terminal's speed and session's priority when deciding for a vertical handover session from WiMAX to WLAN.

4. Performance Evaluation

In our simulations, for the purpose of testing the above proposed vertical handover decision algorithm, we use a two-tier heterogeneous wireless network structure that is composed of a WiMAX cell overlaying a WLAN hotspot. The simulation study was conducted by simulating 30 mobile terminal nodes attached to the WiMAX network. Detailed characteristics of the simulation parameters are explained in Table 1.

The network topology and an example of the type of trajectories of the mobile nodes are shown in Figure 2 and Figure 3. Detailed characteristics of the movement of the mobile node terminals are given in Table 2. 6 of 30 mobile node terminals that are moving in WiMAX and WLAN coverage require MPEG-4, FTP and Telnet traffic. The other 24 terminals are using VoIP G.711 traffic. In the beginning of the simulation runs all 30 mobile node terminals are attached to WiMAX base station. After some time they move through the WLAN coverage performing vertical handovers between WiMAX and wireless LAN.

Using this model each node moves along a straight line from some starting point to some end point. We use 4 types of traffic in the simulations as examples of conversational, streaming, web and background traffic. They are VoIP G.711, MPEG-4, Telnet and FTP sessions. VoIP G.711 traffic is simulated with a packet size of 160 bytes at the application layer and inter-arrival packet time of 20 ms. VoIP G.711 and MPEG-4 are considered in the study as sessions with high priority, because they are real-time traffic types. Telnet and FTP are considered as sessions with low priority, and they are non-real-time traffic types. The propagation model is *TwoRayGround*, considering both the direct path and a ground reflection path. The total simulation time is 200 seconds.

Table 1. Simulation Parameters

Name of the parameter	Value of the parameter
Simulation range	2000 m x 2000 m
Simulation duration	200 seconds
Transmission radiuses of WiMAX (IEEE 802.16)	500 meters
802.16 BS Transmission power	0.025 W
MAC/802.16 scan interval	50 seconds
MAC/802.16 UCD interval	5 seconds
MAC/802.16 DCD interval	5 seconds
802.16 RXThresh	2.025e-12 W
802.16 CSThresh	0.9 x RXThresh
Transmission radiuses of WLAN (IEEE 802.11)	50 meters
Frequency of WLAN	2.412 GHz
Bit rate of WLAN	11 Mbps
802.11 AP Transmission power	0.0134 W
802.11 RXThresh	5.25089e-10 W
802.11 CSThresh	0.9 x RXThresh
Antenna	Omni Antenna
Propagation model	TwoRayGround

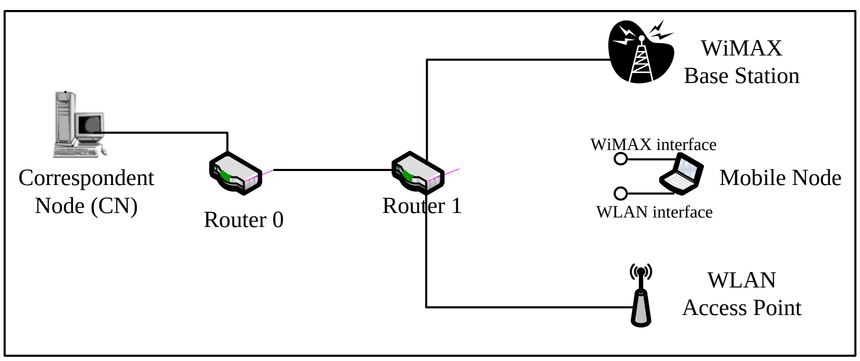

Figure 2. Heterogeneous Network Topology

Firstly, the simulations are done without applying our designed algorithm using provided IEEE 802.21 add-on module [9] for vertical handovers between WiMAX and WLAN. After analysis of the results we applied our vertical handover decision algorithm and made simulations using the same simulation scenario. Compared results of the QoS performances of average throughput, packet loss and vertical handover latency are shown in Figure 4, Figure 5 and Table 3.

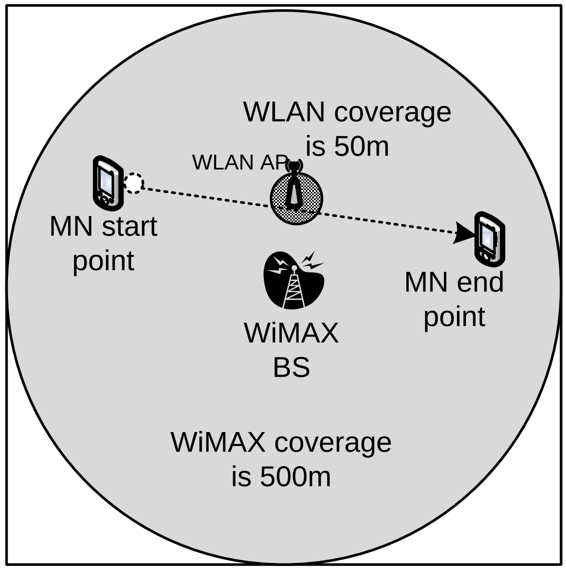

Figure 3. Heterogeneous Network Scenario with 30 Mobile Terminals

When we have simulated the specific scenario without applying our algorithm and using just the 802.21 simulator from NIST, 30 vertical handovers were triggered between WiMAX cell and WLAN hotspot. After the implementation of our algorithm in the specific scenario the number of vertical handovers was decreased to only 4. It occurred only for the mobile terminal nodes that were moving with speed equal or below the threshold speed and that were using low priority sessions.

Table 2. Types of Mobile Nodes

Mobile terminals	Velocity of the MN [kmph]	Type of Movement	Type of traffic
1, 2	3.6	Starting in WiMAX, crossing through WLAN, ending in WiMAX	MPEG-4
3, 4	3.6	Starting in WiMAX, crossing through WLAN, ending in WiMAX	FTP
5, 6	3.6	Starting in WiMAX, crossing through WLAN, ending in WiMAX	Telnet
7-10	5	Starting in WiMAX, crossing through WLAN, ending in WiMAX	VoIP G.711
11-14	10	Starting in WiMAX, crossing through WLAN, ending in WiMAX	VoIP G.711
15-18	15	Starting in WiMAX, crossing through WLAN, ending in WiMAX	VoIP G.711
19-22	20	Starting in WiMAX, crossing through WLAN, ending in WiMAX	VoIP G.711
23-26	25	Starting in WiMAX, crossing through WLAN, ending in WiMAX	VoIP G.711
27-30	30	Starting in WiMAX, crossing through WLAN, ending in WiMAX	VoIP G.711

The value of the threshold speed is 10 kmph. The reason why we choosed this threshold speed is because with higher speeds there is no need to process the vertical handovers to small cells like WLAN, because the users will be covered in a short time period. Furthermore, the WLAN network is more sensitive to higher speeds of the mobile terminals.

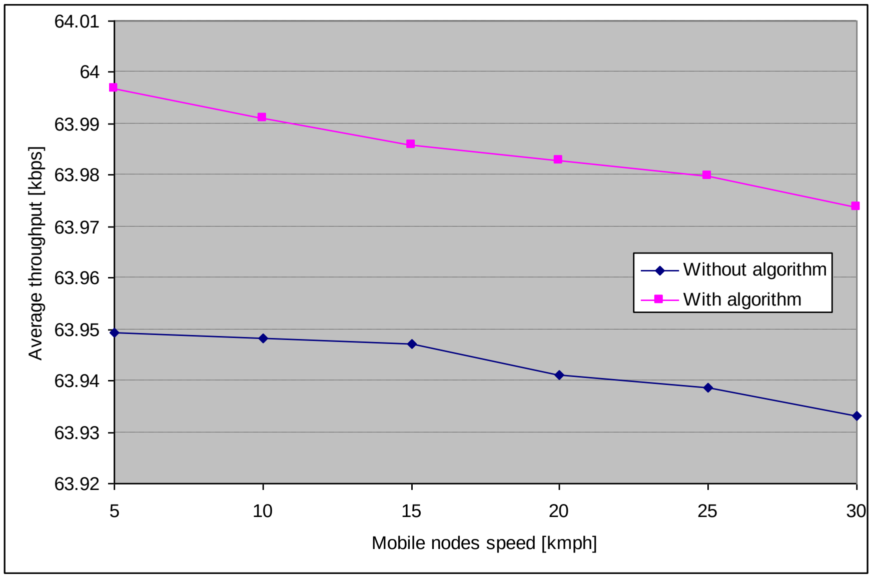

Figure 4. Average Throughput of the VoIP users while moving through WiMAX with and without Algorithm

Performance study after the implemention of our algorithm was done considering the metrics vertical handover latency expressed in milliseconds, packet loss expressed in % and average throughput expressed in kbps. The handover performance study after the implemention of our algorithm was done considering only the metric vertical handover latency. Vertical handover latency is defined as the difference between the time when the mobile node is last able to send or receive an IP packet by way of the previous WiMAX network, and the time when the mobile node is able to send or receive an IP packet through the new WLAN network.

Figure 4 shows the average throughput of the mobile terminals that use VoIP G.711 traffic (7^{th} to 30^{th} mobile terminal) while they are attached to WiMAX network before and after applying the algorithm. Results for the average throughput in Figures 4 and 5 are obtained after 10 simulation iterations.

Before applying the algorithm 24 mobile terminals that use VoIP traffic are crossing to WLAN network according their trajectories and perform vertical handovers to WLAN. After applying the algorithm neither of these 24 VoIP mobile users performs vertical handover, although they are crossing to WLAN coverage. This happens because 16 of them move with speed above 10 kmph, so they are staying in WiMAX network when they are detecting the WLAN coverage according the algorithm decision. The other 8 mobile users are fulfilling the first condition of the algorithm, but they use traffic with high priority, so they also do not perform vertical handover to WLAN. It is obvious from the graph in Figure 4 that if we don't apply our algorithm average throughput of the VoIP mobile users is lower.

The values for the average speed in Figure 4 are obtained in this way. The average throughput for each user is obtained by averaging the instantaneous throughput every 100 ms during the simulation of 200 seconds. Because every 4 VoIP mobile users move with speeds from 5 to 30 kmph with step of 5 kmph (see in Table 2), the values on the y-graph for the average throughput in Figure 4 for each speed from 5 to 30 kmph are averaged values of 4 VoIP mobile users moving with the same speed. The implementation of our proposed vertical handover decision algorithm improves the results for average throughput of the VoIP mobile users moving for each of the simulated speeds. Methodology for obtaining the results in Figure 5 is the same as in Figure 4.

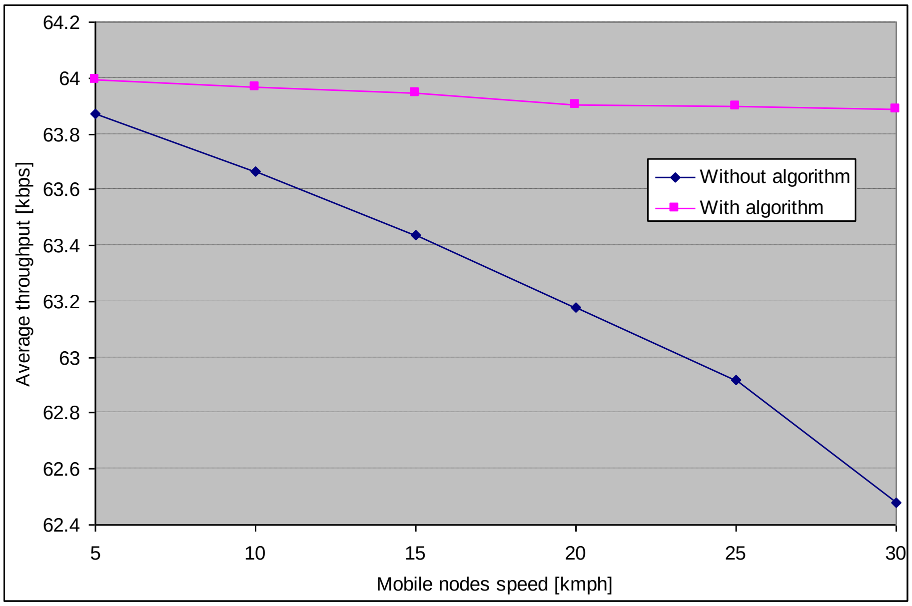

Figure 5. Average Throughput of the VoIP users while moving cross WLAN Coverage with and without the Algorithm

The results for the average throughput in Figure 5 are given when VoIP mobile users are moving in the WLAN coverage. It is clearly shown in the graph that without the algorithm when VoIP mobile terminals are using WLAN network, the average throughput degrades when the speed increases. It is because the WLAN technology is sensitive when the users move with higher speeds. After applying our algorithm we have improved the results for average throughput when VoIP mobile terminals are attached to WiMAX network during the time they are crossing the WLAN cell. Results are improved because vertical handover process is avoided although the VoIP users are located in the WLAN coverage. They can still use the WiMAX network, so there is no need to perform vertical handover to the WLAN access point. These facts and the improved results for average throughput justify the benefit of our algorithm.

It is obvious from the obtained results that we analyze the implementation of the vertical handover decision algorithm on different aspects of the simulated scenario. The packet loss in Figure 6 is analyzed for the VoIP users only when they are attached to the WiMAX network before and after the implementation of the algorithm. The results from ten simulation iterations are presented in the graph. Before applying the algorithm the VoIP users spend less time in WiMAX network because they are performing vertical handovers to the WLAN network and they are using the access point from WLAN for a while.

The results in Figure 6 are obtained in this way. The packet loss is calculated for each of the 24 VoIP users moving with speeds from 5 to 30 kmph with step of 5 kmph, as shown in Table 2. The averaged values for packet loss of every 4 VoIP mobile terminals that move with the same speed (from 7th to 30th user in Table 2) are presented in the y-graph in Figure 6. The comparison results show that the implemented algorithm improved the packet loss of the VoIP traffic while the mobile terminals are attached to WiMAX network. The results are improved because before applying our algorithm, the vertical handover process to WLAN of

24 VoIP users in the scenario increased the packet loss. According the decisions of the new vertical handover algorithm these users do not make vertical handovers to the WLAN access point. So, when the mobile users stay in WiMAX network the packet loss is lower. It is clearly shown in Figure 6.

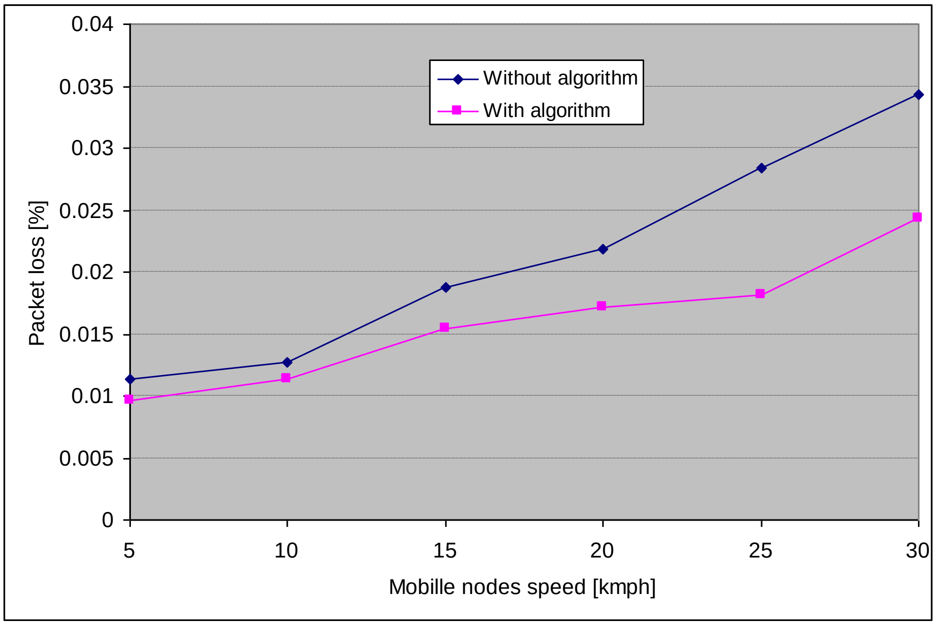

Figure 6. Packet Loss of the VoIP users while they are Attached to WiMAX network with and without the Algorithm

The difference in packet loss before and after applying the algorithm is greater when mobile nodes move with higher speed. Higher speed of the mobile nodes causes higher vertical handover latency and higher vertical handover time. As a result of that, the packet loss of the VoIP mobile users while they are attached to the WiMAX before applying the vertical handover decision algorithm increases sharply as speed of the mobile nodes increases.

Table 3 compares the average values for vertical handover latency without and with our added vertical handover decision algorithm during the vertical handover process. The values are averaged for terminals that use FTP and Telnet traffic. They are all moving with a same speed of 3.6 kmph. We cannot compare the results for vertical handover latency of 24 mobile terminals that use VoIP traffic and 2 mobile terminals that use MPEG-4 traffic, because the vertical handovers hasn't been triggered between WiMAX and WLAN after adding our algorithm. The results in Table 3 show that the implementation of designed vertical handover decision algorithm in this particular scenario not only decreased unnecessary vertical handovers of the users, but also decreased the vertical handover latency of the mobile terminals that use sessions with low priority.

Table 3. Average Vertical Handover Latency

Averaged results after 10 iterations	Vertical handover latency between WiMAX and WLAN [ms]	
	Without algorithm	With applied algorithm
Averaged results of 2 mobile terminals using FTP traffic	416.66	409.95
Averaged results of 2 mobile terminals using Telnet traffic	244.04	207.5

This happens due to the fact that before the implementation of the vertical handover decision algorithm in this specific scenario all of the mobile users performed vertical handover process from WiMAX to WLAN. As a consequence, vertical handover latency for some of them will increase because of the congestion. When some users start to perform vertical handovers other users are already in the process of vertical handover, and they must wait for more time to finish the procedure of disconnecting from WiMAX and connecting to WLAN network. When fewer users perform vertical handovers, probability of this kind of problems decreases. Hence, vertical handover latency decreases, as it is shown in the obtained results in Table 3.

5. Conclusion

Effective vertical handover decision strategy is more than needed in the heterogeneous WiMAX/WLAN networks which can combine their advantages on data rates and coverage, offering the best QoS to the mobile users. WLAN is designed for low mobility, high-medium data rate access, low range and therefore can be used as a complement to the larger WiMAX network. In this paper, we have proposed a vertical handover decision algorithm that uses mobile node speed and session priority when making decision for vertical handover to WLAN network from WiMAX. The algorithm is integrated with the IEEE 802.21 standard modifying NIST simulation package [9]. By testing the proposed algorithm in a simulation scenario with mixed traffic and different moving speed of the mobile nodes we reduced the vertical handover latency and packet loss and improved the average throughput results of the mobile users. Proposed vertical handover decision algorithm reduces unnecessary vertical handover procedures to WLAN network when we have complex simulation scenarios with different moving speeds and types of traffic of the mobile users.

The contribution of this paper is in improving the QoS results when dual mode WiMAX/WLAN terminals are performing vertical handovers from WiMAX to WLAN hotspots. Our main goal was to improve the QoS of the mobile users that utilize complementary WiMAX/WLAN coverage, with the design of the vertical handover decision algorithm that can be easily implemented in the resource management for heterogeneous networks. We practically applied the algorithm in the already existing NIST simulation tool for 802.21 and practically tested it with 30 mobile terminals that use conversational, streaming, web and background traffic. We proved that with the implementation of this vertical handover decision algorithm we can avoid unnecessary vertical handovers to WLAN network and improve the vertical handover latency, packet loss and average throughput of the mobile users which are very important metrics, especially for real time sessions.

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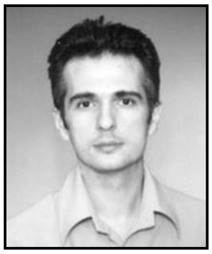

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Dr. Toni Janevski is a Full Professor at the Faculty of Electrical Engineering and Information Technologies, Ss. Cyril and Methodius University in Skopje, Macedonia. He received his Dipl. Ing., M.Sc. and Ph.D. degrees in electrical engineering all from Faculty of Electrical Engineering and Information Technologies, Ss. Cyril and Methodius University in Skopje, in 1996, 1999 and 2001, respectively. In the past, during 1996-1999 he has worked at the Macedonian mobile operator Mobimak (currently T-Mobile, Macedonia), contributing to the planning, dimensioning and implementation of the first mobile network in Macedonia. From 1999 he is with Faculty of Electrical Engineering and Information Technologies in Skopje. In 2001 he has conducted research in optical communication at IBM T. J. Watson Research Center, New York. Also, during 2005-2008 he was a Member of the Commission of the Agency for Electronic Communications (AEC) of the Republic of Macedonia, where he contributed towards the introduction of new technologies in Macedonia, such as WiMAX and 3G mobile networks, as well as new operators and services. During the periods 2008-2012 and 2012-2016 he is an elected member of the Senate of the Ss. Cyril and Methodius University in Skopje. In 2009 he has established Macedonian ITU (International Telecommunication Union) Centre of Excellence (CoE) as part of the Europe's CoE network, and serves as its Coordinator since than. He is an author of the book titled "Traffic Analysis and Design of Wireless IP Networks", which is published in 2003 by Artech House Inc, Boston, USA. Also, he is author of the book "Switching and Routing", written in Macedonian language, published in September 2011 by the Ss. Cyril and Methodius University in Skopje, for which in May 2012 he has won the "Goce Delchev" award, the highest award for science in the Republic of Macedonia. He has published more than 130 research papers and has led research and applicative projects in the area of Internet technologies and mobile and wireless networks. He is a Senior Member of IEEE. His research interests include Internet Technologies, Mobile, Wireless and Multimedia Networks, Traffic Theory, Quality of Service, Design and Modeling of Telecommunication Networks, as well as Next Generation Networks.