Czech Technical University

Department of Telecommunication Engineering

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Fuzzy logic in handovers of Mobile WiMAX

Project submitted in the degree Enginyeria Superior de Telecomunicacions a Barcelona

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Preface

This thesis was carried out in the Department of Telecommunications Engineering in the Electrical Faculty of Czech Technical University.

First I would like to thank the department to give me a topic to work with. I would like to specially thank to my supervisor Ing. Robert Bešťák for his advanced and fast feedback and for providing me material that helped in my investigation. I would also like to thank all the investigators who work in the office that help me providing me material and create a perfect atmosphere of working.

I thank to all my friends that I made here who helped and supported me and make me believe as if I was at home. Finally I specially thank to my family that supported me during all this years that lasted my university degree.

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1. Introduction

Telecommunication industries have focused in broadband systems, which are characterized by a high quality features. Broadband wireless access has become the fastest way to get fast internet connection and ‘triple play’ services.

One of the biggest problems of first wireless networks was radio coverage. In order to solve it, WiMAX Forum was created to develop a WMAN standard. First was created IEEE 802.16d-2004, also called fixed WiMAX. One year later WiMAX Forum presented IEEE 802.16e-2005 standard, which gave to the costumer the possibility of movement using the same applications and also having ‘triple play’ services.

As all the mobile communications, one of the biggest problems faced by Mobile WiMAX is the handover between the Mobile Station and the different base stations. In order to improve and find a solution economic and more efficient, we are going to develop a fuzzy logic system.

The idea is to create a system with two inputs, after this the fuzzy logic rules will give us a solution for the decision of the handover. With this solution the algorithm will try to do the handover if it is necessary and possible. The idea is get results comparing with the usual handover that consists in a determined threshold of one parameter and then decide.

First of all we will introduce some previous definitions necessary to understand the theoretical part of Mobile WiMAX, and then we will talk about Mobile WiMAX characteristics, most of them shared with fixed WiMAX. After this we will enter in the handovers of WiMAX, discovering the process made between the BS and the MS.

After introducing WiMAX we will introduce the basic features of fuzzy logic. Having introduced all the theoretical aspects, we will explain how the algorithm works and which the main characteristics of the mobile stations are.

Then we will introduce the results of the simulation and also evaluate the simulation changing some features of the mobile, in order to evaluate the reliability of the fuzzy logic algorithm

Finally we will arrive to the conclusion and discuss if the fuzzy logic is a necessary improvement for the handovers in mobile WiMAX.

2. Previous definitions

- Orthogonal Frequency Division Multiplexing (OFDM): is a broadband multicarrier modulation method that offers superior performance and benefits over older, more traditional single-carrier modulation methods because it is a better fit with today's high-speed data requirements and operation in the UHF and microwave spectrum [1]. The multiuse-version of OFDM is called Orthogonal Frequency-Division Multiple Access (OFDMA), and it is achieved by assigning subsets of subcarriers to individual users. In figure 1 we can see the difference between single-carrier mode and multiple subcarrier mode. In one subcarrier mode, we can see that the user only works with one frequency, and if this is busy, no other user can enter. Δf represents the frequency periods, inverse of time period. The example of OFDM of 6 subcarriers, we can see the way that more than one user can work giving them different frequencies.

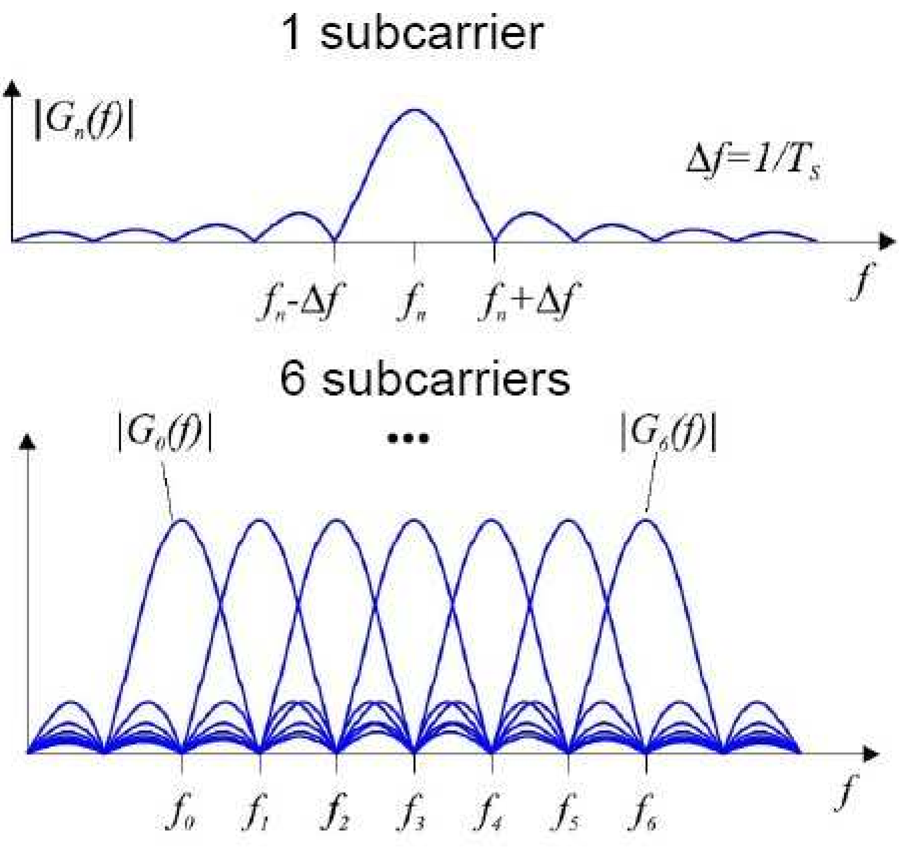

Fig1. Difference between single-carrier and OFDM modulation

- Fast Fourier Transform (FFT): The FFT is a discrete Fourier transform algorithm which reduces the number of computations needed for N points from $2N^2$ to $2N\lg N$, where lg is the base-2 logarithm, where N is the number of computations desired to make the transform. If the function to be transformed is not harmonically related to the sampling frequency, the response of an FFT looks like a sinc function (although the integrated power is still correct) [2]

- Adaptative Modulation and Coding (AMC): AMC provides the flexibility to match the modulation-coding scheme to the average channel conditions for each user. With AMC, the power of the transmitted signal is held constant over a frame interval, and the modulation and coding format is changed to match the current received signal quality or channel conditions [3]. In figure 2 we can see how AMC works, each color represents a different modulation zone, so when the mobiles moves around the scenario, when it moves the AMC gives the most powerful modulation possible, and if it goes farer from the BS, the MS works with a less powerful modulation in order to keep on working:

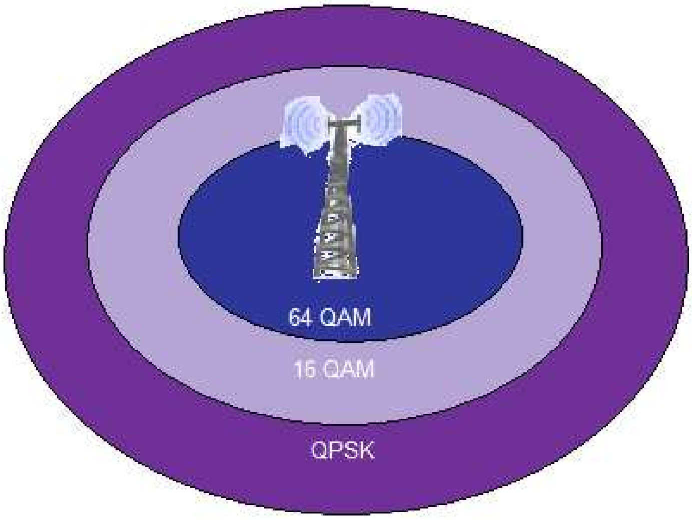

Fig2. AMC scheme

- Forward Error Corrections (FEC): is a type of digital signal processing that improves data reliability by introducing a known structure into a data sequence prior to transmission or storage. This structure enables a receiving system to detect and possibly correct errors caused by corruption from the channel and the receiver [4]
- Hybrid Automatic Retransmission Requests (HARQ): is a technology used to improve the error performance and increase the spectral efficiency of wireless communication systems, and hence, they are widely adopted in next generation wireless systems [5]

- Low-Density Parity-Check (LDPC) Codes: can be described by a bipartite graph, in which the bit nodes and the check nodes represent the information bits and the parity check equations respectively [6]
- Advanced Antenna Systems (AAS): consists in transmitting diversity in the downlink, it is achieved by defining a number of space-time block coding schemes. Beamforming can provide significant improvement in the coverage range, capacity, and reliability [7]
- Advanced Encryption Standard (AES): is a symmetric block cipher that can encrypt (encipher) and decrypt (decipher) information. Encryption converts data to an unintelligible form called ciphertext; decrypting the ciphertextconverts the data back into its original form, called plaintext.[8]
- Extensible Authentication Protocol (EAP): provides an infrastructure for network access clients and authentication servers to host plug-in modules for current and future authentication methods [9]

3. Basic features of Mobile WiMAX

3.1 Basic features

WiMAX (Worldwide Interoperability for Microwave Access) is based on Wireless Metropolitan Area Networking (WMAN) standards developed by the Institute of Electrical and Electronics Engineers (IEEE) 802.16 group and adopted by both IEEE and the European Telecommunications Standards Institute High Performance Radio Metropolitan Area Network (ETSI HIPERMAN) group. The standard was created in 1998. After some evolutions, in 2005 mobility support was added.

IEEE 802.16-2005 works in two bands, between 2-11 GHz for fixed applications and between 2-6 GHz for mobile applications; both kind of applications can be Non-Line-Of-Sight (NLOS). In figure 3 we can see the reference model of Open System Interconnection (OSI), Mobile WiMAX works in the first two levels marked in black and with a yellow background, physical and MAC levels, for this we will focus in these two layers.

Application
Presentation
Session
Transport
Network (IP)
MAC
Physical

Fig3. OSI Reference Model levels, reference [10]

3.1.1 Physical layer

Mobile WiMAX works in different bands, the lower band works between 2.3 Gigahertz (GHz) and 2.4 GHz; and the higher between 3.6-3.8 GHz. Each band has the option of working with different bandwidths. Each combination of frequency band plus the bandwidth has OFDM FFT (Fast Fourier Transform) size, 512 or 1024. All the combinations work with a duplexing of TDD (Time Division Duplexing). Although TDD is often preferred, FDD (Frequency Division Duplexing) profiles may be needed in the future to comply with regulatory paring and interoperator coexistence requirements in certain bands.

One of the main characteristics of mobile WiMAX compared with fixed is the transmission scheme; mobile WiMAX uses different options: single carrier, 256 OFDM or scalable OFDM with 128, 512, 1024 or 2048 subcarriers. Modulations used are the same in all kind of WiMAX, QPSK (Quadrature Phase-Shift Keying), 16 QAM (Quadrature Amplitude Modulation) and 64 QAM. In table 1 we can see the modulations that Mobile WiMAX can work with, also the coding rate for each modulation and the Signal-Noise Ratio (SNR) needed for each combination of modulation and coding rate:

Modulation	Coding Rate	Receiver (dB)
QPSK	½	6.0
	¾	8.5
16 QAM	½	11.5
	¾	15.0
64 QAM	½	19.0
	¾	21.0

Table1. SNR needed for each modulation, reference [11]

Other features to be considered are the data rate, which is 1-75 Mbps; multiplexing options, burst TDD/FDD/OFDMA (Orthogonal Frequency Duplexing Mode Access); duplexing, TDD and FDD and channel bandwidths, 1.75 Megahertz (MHz), 3.5 MHz, 7 MHz, 14 MHz, 1.25 MHz, 5 MHz, 10 MHz, 15 MHz, 8.75 MHz. The air-interface designation has also different possibilities, WirelessMAN-SCa, WirelessMAN-OFDM, WirelessMAN-OFDMA and WirelessHUMAN; finally the WiMAX implementation is made with Scalable OFDMA.

All mobile WiMAX profiles use scalable OFDMA in the physical layer. At least initially, all mobility profiles will use a point-multipoint Media Access Control (MAC).

Uplink and downlink resource allocation are controlled by a scheduler in the base station. Capacity is shared among multiple users on a demand basis, using a burst TDM scheme. When using the OFDMA-PHY mode, multiplexing is additionally done in the frequency dimension, by allocating different subsets of OFDM subcarriers to different users. Resources may be allocated in the spatial domain as well when using the optional AAS. The standard allows for bandwidth resources to be allocated in time, frequency, and space. In figure 4 we can see how the vertical encoding is done with AAS, where the multiple streams are coded and modulated together before being presented to the space/time encoding block:

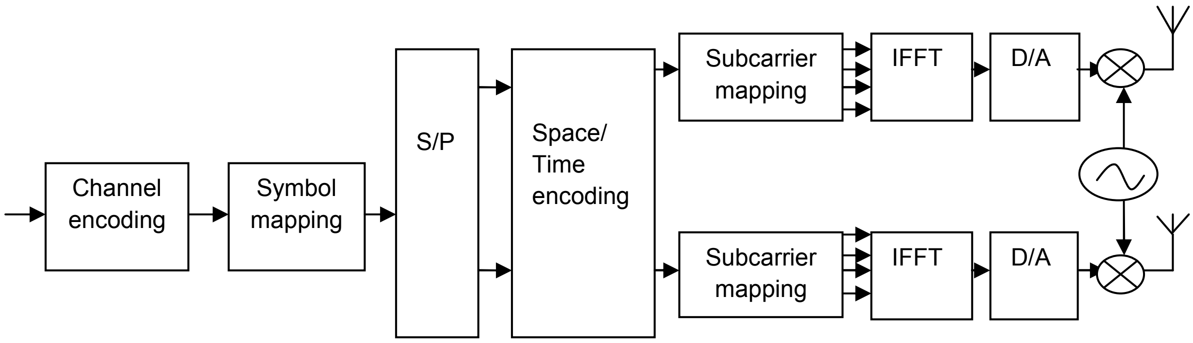

Fig4. Vertical encoding for two antennas in diversity mode, reference [7]

When AAS is used in the open-loop the multiple antennas can be used for diversity, in the closed-loop mode the multiple antennas due to channel reciprocity, in the case of TDD; or to explicit feedback from the receiver, in the case of FDD. Transmit Diversity and Space/Time Coding:

- The most commonly implemented are the two antenna open-loop schemes
- For transmit diversity modes with a space/time code rate greater than 1, both horizontal and vertical encoding are allowed

Frequency-Hopping Diversity Code:

- Optional mode, which using two antennas in which the encoding is done in the space and frequency domain

Other important characteristic is the ranging option. It is an uplink procedure that maintains the quality and reliability of the radio-link communication between the BS and the MS. It allows the BS to indicate to the MS any adjustments in the transmit power level or the timing offset that it might need relative to the BS.

Two OFDM symbols are created. The first OFDM symbol is created as any normal OFDM symbol. The second one is created by performing an Inverse Fast Fourier Transform (IFFT) on the same ranging code and by then appending, at the end, a segment of length Tg from the beginning of the symbol. With this we ensure no phase discontinuity.

In order to increase the ranging capacity, MS can optionally use two consecutives ranging codes transmitted over four OFDM symbol periods.

Strong Quality of Service (QoS) control is achieved by using connection-oriented MAC architecture. Before any data transmission, the MS and the BS establish a unidirectional link, called connection, between the two MAC-layer peers. It is defined a service flow with a unidirectional flow of packets with a particular set of QoS parameters and is identified by a Service Flow Identifier (SFID).

3.1.2. MAC layer

Focusing on the MAC layer, we can say that the packets are organized the packets into MAC Protocol Data Units (MPDUs), the receiver makes the reverse process. MAC design includes a convergence sublayer that can interface with a variety of higher-layer protocols, Asynchronous Transfer Mode (ATM), Internet Protocol (IP), Ethernet…. It uses a variable-length MPDU and offers a lot of flexibility to allow for their efficient transmission. Multiple MPDUs of same or different lengths may be aggregated into a single burst to save PHY overhead. In figure 5 we can see how MPDUs are created, focusing than different packets are fragmented, and they can be joined in different PDUs:

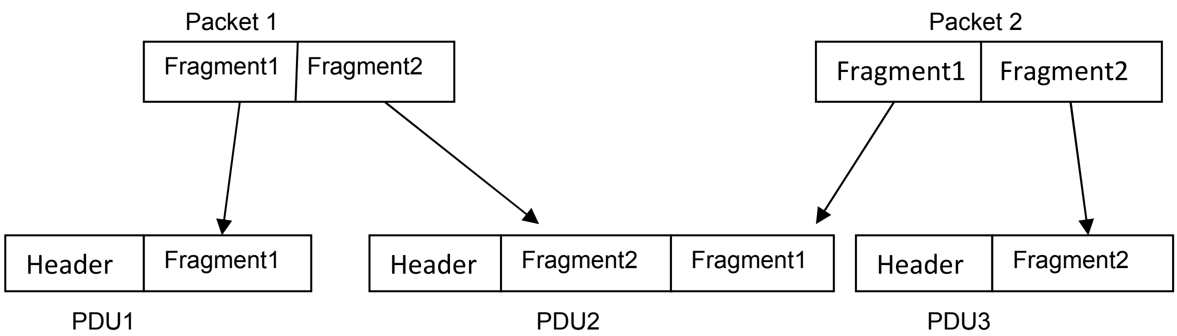

Fig5. Concatenation of packets in PDUs, reference [7]

It is the responsible for allocating bandwidth to all users (the only time that the Mobile Station (MS) controls the bandwidth is when it has multiple connections to the Base Station (BS)). The BS allocates dedicated or shared resources periodically to each MS, this process is called polling.

Another important feature is the AMC; WiMAX supports a number of modulation and FEC coding schemes and allows the scheme to be changed on per user and per frame basis, based on channel conditions. AMC is an effective mechanism to maximize throughput in a time-varying channel. The adaptation algorithm typically calls for the use of highest modulation and coding scheme that can be supported by the signal-to-noise and interference ratio at the receiver such that each user is provided with the highest possible data rate.

For the connections that require enhanced reliability, WiMAX supports Automatic Retransmission Requests (ARQ) at the link layer. ARQ-enabled connections require each transmitted packet to be acknowledged by the receiver; unacknowledged packets are assumed to be lost and retransmitted. Two types of HARQ:

- Type I: also referred to as chase combining, the redundancy version of the encoded bits is not changed from one transmission to the next: the puncturing pattern remains same. The receiver uses the current and all previous HARQ transmissions of the data block in order to decode it. When the data block cannot be decoded without error and the maximum number of HARQ transmission is reached, a higher layer retransmits the data block.
- Type II: also referred to as incremental redundancy, the redundancy version of the encoded bits is changed from one transmission to the next, the puncturing pattern changes from one transmission to the next.

Interleaving is when the encoded bits are encoded in two-step process; the two steps are done independently in each FEC block. The first step ensures that the adjacent bits are mapped on nonadjacent subcarriers, providing frequency diversity and improves the performance of the decoder. The second step ensures that adjacent bits are alternately mapped to less and more significant bits of the modulation constellation. When turbo codes are used, the interleaver is bypasses, since a subblock interleaver is used within the encoder.

Security

WiMAX supports strong encryption using AES, and has a robust privacy and key-management protocol. The system also offers very flexible authentication architecture based on EAP, which allows for a variety user credentials.

The mobile WiMAX variant of the system has a mechanism to support secure seamless handovers for delay-tolerant full-mobility applications, such as Voice over Internet Protocol (VoIP). The system also has built-in support for power-saving mechanisms that extend the battery life of handheld subscriber devices. Physical-layer enhancements, such as more frequent channel estimation, uplink subchannelization, and power control, are also specified in support of mobile applications. In figure 6 we can see summarized of the security features used by Mobile WiMAX:

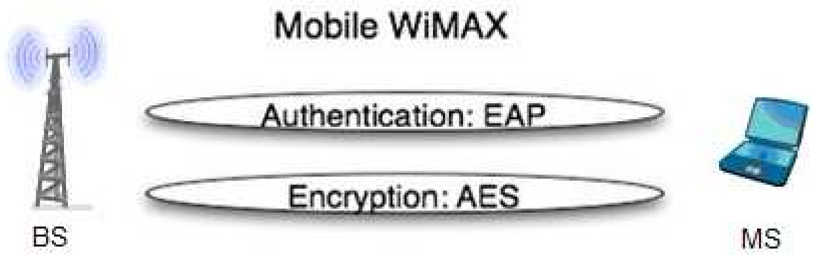

Fig6. Security features of Mobile WiMAX, reference [12]

In order to increase the security, channel encoding is used. Five steps: data randomization, channel coding, rate matching, HARQ, and optionally interleaving. Data randomization:

- Performed in the downlink and the uplink using the output of a maximum-length shift-register sequence that is initialized at the beginning of every FEC block, this shift-register is added with the data sequence to create randomized data.
- The purpose is to provide layer 1 encryption and to prevent a rogue receiver from decoding the data.
- Channel coding is performed on each FEC block, which consists of an integer number of subchannels. The maximum number of subchannels depends on the channel coding scheme and the modulation constellation, if it is bigger than this maximum, the FEC block is segmented into multiple FEC-subblocks, these subblocks are encoded and rated matched separately and the concatenated sequentially.
- Convolutional coding: uses a constituent encoder with a constraint length 7 and native rate ½. In the downlink of the OFDM mode, the output of the data randomizer is first encoded using an outer systematic Reed Solomon code and then encoded using an inner rate ½ binary convolutional encoder.
- Turbo codes: convolutional turbo codes are worth describing because of their superior performance and high popularity in other broadband wireless systems. WiMAX uses duobinary turbo codes with a constituent recursive encoder of constraint length 4. The output of the native R1/3 turbo encoder is separated into six blocks.
- Block Turbo Codes and LDPC Codes: defined as optional channel coding schemes but are unlikely to be implemented in fixed or mobile WiMAX, the

reason is that most equipment manufacturers have decided to implement the convolutional turbo codes for their superior performance over other FEC schemes. The LDPC code can flexibly support various block sizes for each code rate through the use of an expansion factor.

Power Management

Mobile WiMAX introduces new concepts about power management and mobility management. Power management enables the MS to conserve its battery resources. There are two modes available, sleep mode and idle mode

Sleep mode is an optional mode. An MS with active connections negotiates with the BS to temporarily disrupt its connection over the air interface for a predetermined amount of time, called sleep window. Each sleep window is followed by a listen window, during which the MS restores its connection. The period of time when all the MS connections are in their sleep window is referred to as the unavailability interval, during which the MS cannot receive any Down Link (DL) or send any Up Link (UL) transmission. Three power-saving classes:

- Power-saving class 1: each listen window of fixed length is followed by a sleep window such that its length is twice the length of the previous sleep window. Recommended for best-effort or non-real-time traffic.
- Power-saving class 2: all sleep windows are of fixed length and are followed by a listen window of fixed length. Recommended for Unsolicited Grant Service (UGS) connections
- Power-saving class 3: consists of a single sleep window. The time is indicated by the BS before entering in this mode. Recommended for multitrafic of for MAC management

The idle mode is a mechanism that allows the MS to receive broadcast DL transmission from the BS without registering itself with the network. It helps mobile MS by eliminating the need of handoff when it is not involved in any active data session.

In sleep mode handover is allowed, in idle mode it is not. Four mobility-related usage scenarios: from non-mobility to mobility up to 120 kilometers per hour (kmph).

3.2 Handovers in mobile WiMAX

Different type of handovers are defined, one obligatory, called Hard Handover (HHO), and it is the only required to be implemented by the mobile WiMAX initially. HHO implies an abrupt transfer of connection from one BS to another. The MS periodically does a Radio Frequency (RF) scan. Once a handover decision is made, the MS begins synchronization with the downlink transmission of the target BS. In figure 7 we can see how hard handover works; in the continuous line is the connection with the BS, in the pointed we see the objective, when the MS advances, breaks the connection with the first BS and establish the new one.

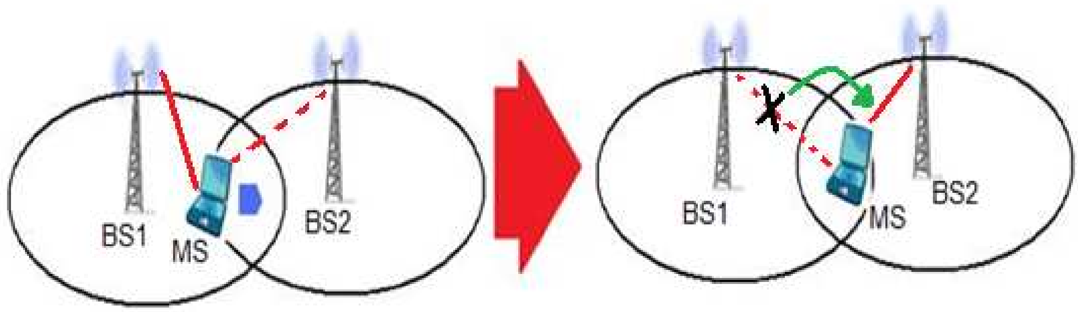

Fig7. Scheme of hard handover

The two optional handover methods supported in IEEE 80.16e-2005 are Fast Base Station Switching (FBSS) and Macro Diversity Handover (MDHO). In these two methods, the MS maintains a valid connection simultaneously with more than one BS. In figure 8 we can see that in that type of HO, the MS is connected simultaneously with more than one BS, it is an example where the mobile station is connected with 3 BS, but the number of BS can be modified:

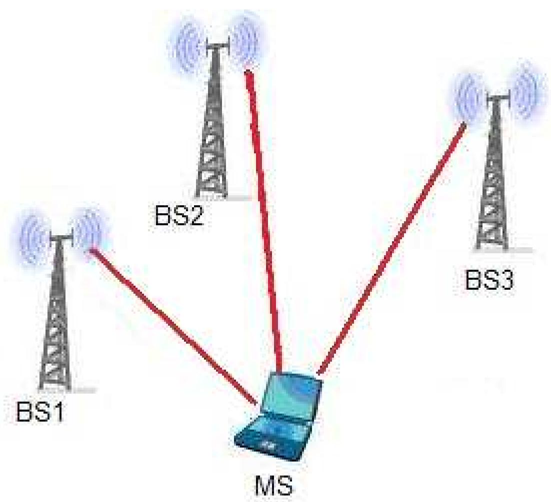

Fig8. Optional handovers scheme

The main difference between MDHO and FBSS remains in what is the function of the different BS. In MDHO, the BSs exchange traffic with the MS and processed. In FBSS, only one BS processes the information, the other information that comes from the different BSs is processed in the MS. So the difference remains in where the information is processed.

This simulation will be based in HHO, in order to focus on the algorithm of fuzzy logic. The implementation of one of these optional techniques will improve the efficiency of the handovers.

The handover procedure requires support form layer 1, 2 and 3 of the network. The decision is taken by layer 3, but layer 1 and 2 play a crucial role providing information and triggers required. The BS allocates time each MS to monitor and measure the radio condition of the neighboring BSs, process called scanning with a time called scanning interval, this is made with a serial of messages signals that gives to the MS some parameters needed to execute the handover.

BS can direct to perform multiple scanning events. The identity of neighboring BSs and the frequencies that a MS is required to scan are provided in a message. During a scanning interval, the MS measures the Received Signal Strength Indicator (RSSI) and the Signal-to-Interference-plus Noise Ratio (SINR) of the neighboring BS and can optionally associate ranging some or all the BSs in the neighbor list. Three levels of association are possible during the scanning process:

- During association level 0 (scan/association without coordination), the MS performs ranging without coordination from the network. The only ranging interval available to the MS is contention-based scanning. The MS receives an RNG-RSP message indicating success of the ranging with the neighboring BS.
- During association level 1 (scan/association with coordination), the serving BS coordinates the association procedure with the neighboring BS. The network provides the MS with a ranging code and a transmission interval for each of the neighboring BSs. The BS may assign one of these parameters to another MS, but not both, with this collision between various MS are avoided.
- Association level 2 (network assisted association reporting) similar to level 1, after the ranging transmission, the MS does not need to wait for a message from the neighboring BS, this information on PHY offsets will be sent by each neighbor BS to the serving BS, that Bs may aggregate all ranging related information into a single message.

It is also important to speak about the handover process and cell reselection, a set of procedures and decisions that enable an MS to migrate from the air interface of one BS to the air interface of another and consists of the following stages:

- Cell reselection: the MS performs scanning and association with one or more neighboring BSs to determine their suitability as a handover target. After, the MS resumes normal operation with the serving BS
- Handoff decision and initiation: MS decides to migrate its connections from the serving BS to a new target BS. This decision can be taken by the MS, the BS, or some other external entity in the WiMAX network and is dependent on the implementation.

A call drop during the handoff process is defined as the situation in which an MS has stopped communication with its serving BS before the sequence is completed.

Figure 9 shows us an example of a block diagram of the handover decision algorithm:

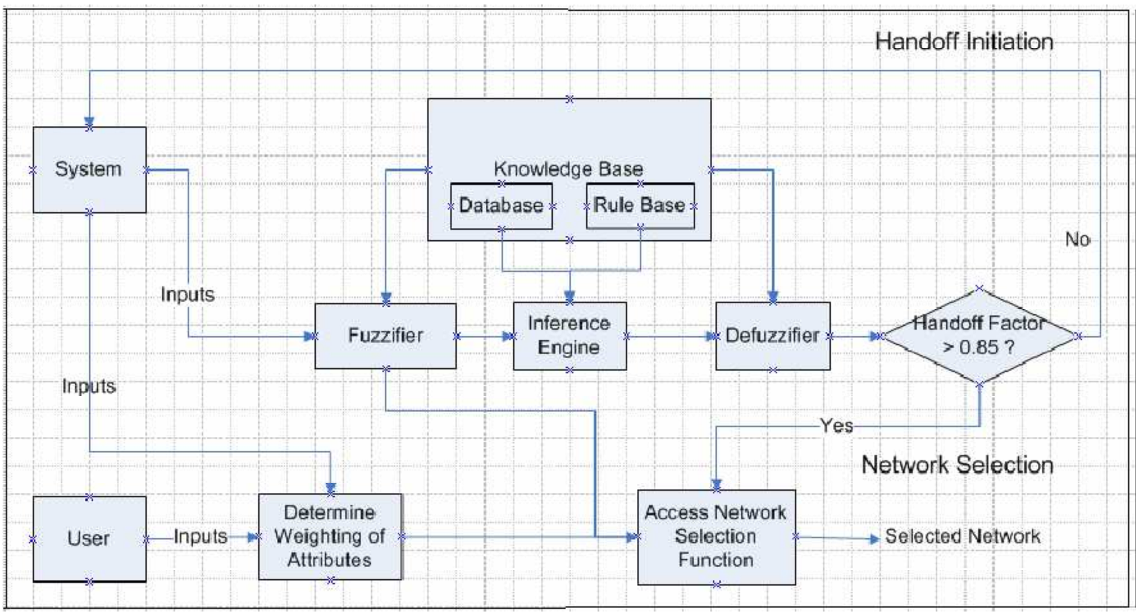

Fig9. Block diagram for Handover Decision Algorithm, reference [13]

The WiMAX mobility-management architecture was designed to:

- Minimize packet loss and handoff latency and maintain packet ordering to support seamless handover even at vehicular speeds
- Comply with the security and trust architecture of IEEE 802.16
- Support MDHO and FBSS
- Minimize the number of round-trips of signaling to execute handover
- Keep handover control and data path control separate
- Support multiple deployment scenarios and be agnostic to ASN decomposition
- Support both IPv4 and IPv6-based mobility management and accommodate mobiles with multiple IP addresses

- Maintain the possibility of vertical or intertechnology handovers and roaming between Network Service Providers (NSP).
- Allow single Network Application Provider (NAP) to serve multiple MSs using different private and public IP domains owned by different NSPs
- Support both static and dynamic home address configuration
- Allow for policy-based and dynamic assignment of home agents to facilitate such features as route optimization and load balancing.

Two kinds of mobility are allowed: Application Service Network (ASN)-anchored mobility and Connectivity Service Network (CSN)-anchored mobility. In ASN-anchored mobility the MS moves between two data paths while maintaining the same anchor foreign agent at the northbound edge of the ASN network. In this case handover happens between R8 and/or R6 reference points, usually involves migration of R6, with R8 used for transferring undelivered packets. In CSN-anchored mobility, the MS changes to a new anchor FA and the new FA exchange signaling messages. In this case the handover happens across the R3 reference point, with tunneling over R4 to transfer undelivered packets. Figure 10 shows us the scheme of the network and here we have the list of the function of each connection:

- R1: Interface between the MS and the ASN. Functionality: Air interface
- R2: Interface between the MS and the CSN. Functionality: AAA, IP host configuration, mobility management
- R3: Interface between the ASN and CSN. Functionality: AAA, policy enforcement, mobility management.
- R4: Interface between ASNs. Functionality: Mobility management.
- R5: Interface between CSNs. Functionality: Inter-networking, roaming.
- R6: Interface between BS and ASN gateway. Functionality: IP tunnel management to establish and release MS connection.
- R8: Interface between BSs. Functionality: Handovers.

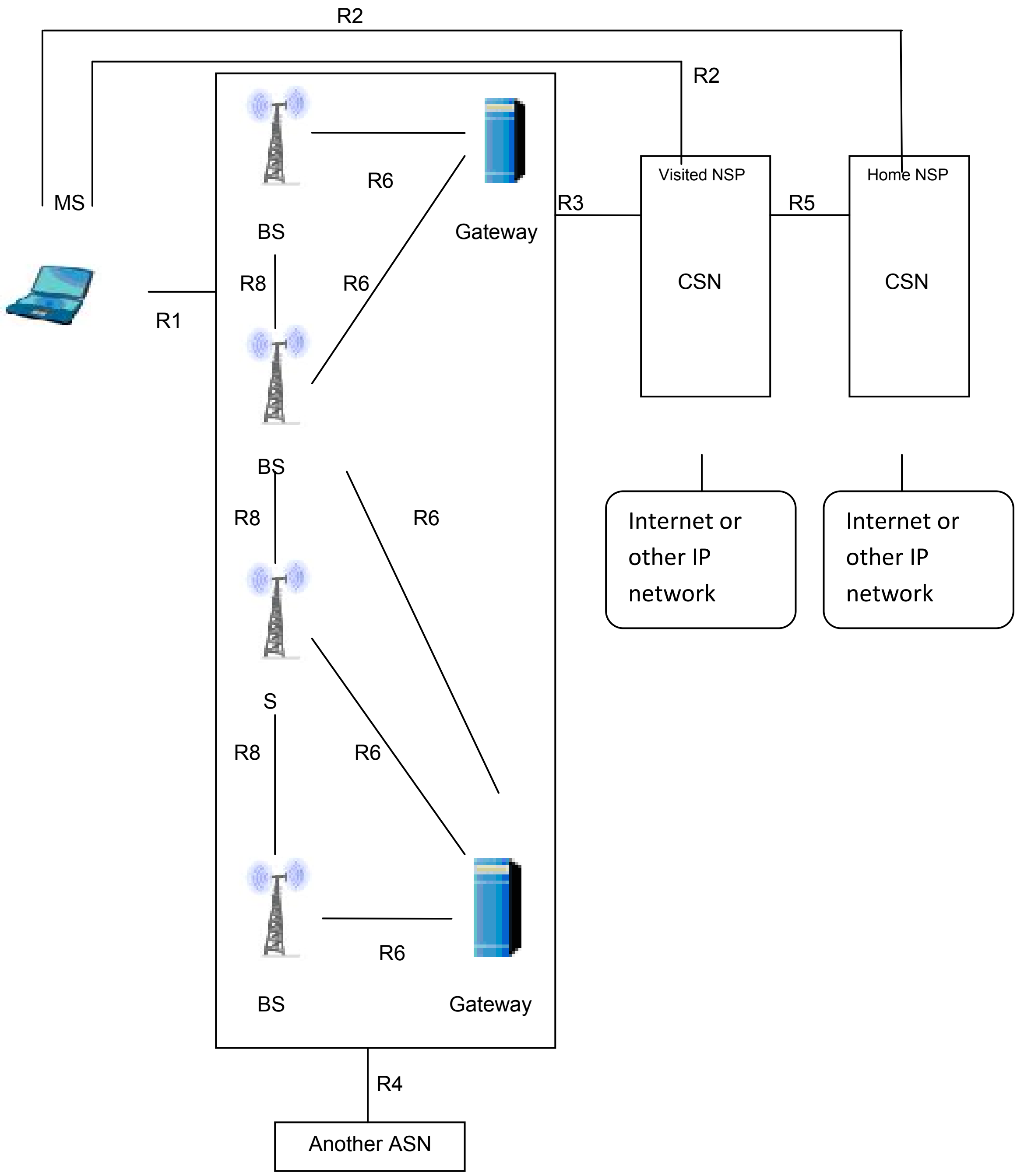

Fig10. Network reference model of WiMAX [7]

4. Basic aspects of fuzzy logic

Fuzzy logic (FL), reference [14], is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers to large, networked, multi-channel PC or workstation-based data acquisition and control systems. It provides a way to arrive at a definite conclusion based upon vague, ambiguous, imprecise, noisy, or missing input information.

In expression 1 we can see the rule-based approach to a solving control problem rather than attempting to model a system mathematically. It is empirically-based, relying on an operator's experience rather than their technical understanding of the system.

IF X AND THEN Y THEN Z (1)

FL requires some numerical parameters in order to operate, but exact values of these numbers are usually not critical unless very responsive performance is required in which case empirical tuning would determine them.

In figure 11, we can see an example of how fuzzy logic works. Here we can see the combination of the two inputs with the rules of expression 1, the combination gives us different possible outputs, and the combination of all gives us a surface that represents all the output.

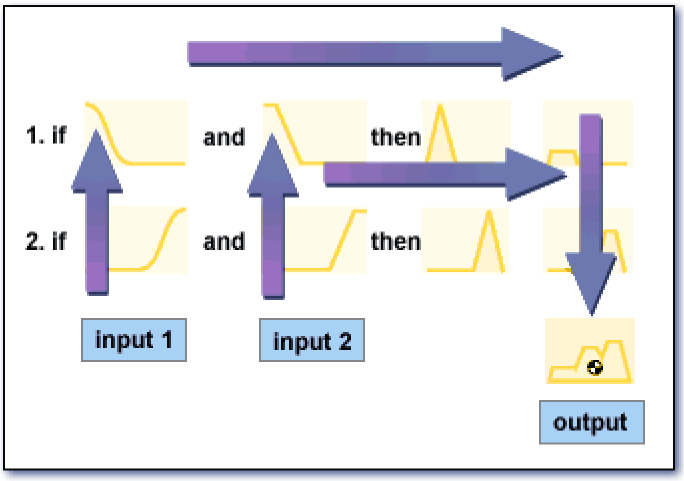

Fig11. Fuzzy logic procedure, reference [15]

Features offered by FL that make it a particularly good choice for many control problems:

- It does not require precise, noise-free inputs and can be programmed to fail safely if a feedback sensor quits or is destroyed. The output control is a smooth control function despite wide range of input variations.
- Rules can be modified and tweaked easily to improve or drastically alter system performance.
- It is not limited to a few feedback inputs and one or two control outputs, nor is it necessary or computes rate-of-change parameters in order for it to be implemented.
- Any reasonable number of inputs can be processed and numerous outputs generated. The best option is to break the control system into smaller chunks and use several smaller FL controllers distributed on the system.
- Can control nonlinear system that would be difficult or impossible to model mathematically.

How is FL used?

- Define the control objectives and criteria
- Determine the input and output relationships and choose a minimum number of variable for input to the FL engine
- Break the control problem down into a series of IF X AND Y THEN Z rules that define the desired system output response for given system input conditions
- Create FL membership functions that define the meaning (values) of Input/Output terms used in the rules.
- Create the necessary pre- and post processing FL routines

Rule matrices usually have an odd number of rows and columns to accommodate a "zero" center row and column region. Membership functions explain us how to apply the rules selected before. The membership function is a graphical representation of the magnitude of participation of each input. The rules use the input membership values as weighting factors to determine their influence on fuzzy output sets of the final output conclusion. After working with them they are defuzzied into a crisp output which drives the system. Some features to note are:

- Shape: triangular is common, but bell, trapezoidal, haversine and, exponential have been used
- Height or magnitude width
- Shouldering
- Center points

- Overlap

The inputs are combined logically using the AND operator to produce output response values for all expected inputs. The active conclusions are then combined into a logical sum for each membership function. A firing strength for each output membership function is computed. All that remains is to combine these logical sums in a defuzzification process to produce the crisp output. The logical products for each rule must be combined or inferred before being passed on to the defuzzification process for crisp output generation. Different inference methods exist:

- Max-Min: tests the magnitudes of each rule and selects the highest one. The horizontal coordinate of the “fuzzy centroid” of the area under that function is takes as the output.
- Max-Dot or Max-Product: the member function(s) are shrunk so that their peak equals the magnitude of their respective function.
- Averaging: each function is clipped at the average and the fuzzy centroid of the composite area is computed
- Root-sum-square: scales the functions at their respective magnitudes, and computes the fuzzy centroid of the composite area. It seems to give the best weighted influence to all firing rules.

The defuzzification of the data into a crisp output is accomplished by combining the results of the interference process and then computing the fuzzy centroid of the area. The weighted strengths of each output member function are multiplied by their respective output membership function center points and summed. Finally, this area is divided by the sum of the weighted member function strengths and the result is taken as the crisp output.

The system can be tuned by changing the rule antecedents or conclusions, changing the centers of the input and/or output membership functions, or adding additional.

5. Theoretical aspects of the simulation

Before taking the results between fuzzy logic decision and usual decision, it is important to explain the different aspects considered in this simulation.

5.1 Scenario and number of mobiles

We have simulated in an area of 3.6 per 5.8 km in order to simulate a city area. In this scenario there are six bases, situated in the center of six squared cells, creating microcells of 2.8 per 2.8 kilometers, with a base station in the center of each microcell. This is simulated with a matrix of 27 per 18 cells and we simulate that each cell is separated 200 m.

To create the mobiles, the algorithm created passes through each cell and creates a mobile if a counter is multiple of one number. In our case, the number is 3, so one of each three cells will have a mobile, this creates 112 mobiles. This decision has been made in order to simulate a urban area.

The distribution will be as it is shown in the figure 12. The bases are located in the position, 1 km/1 km, 1 km/2.8 km, 1 km/4.6 km, 2.8 km/1 km, 2.8 km/ 2.8 km, and 2.8 km/4.6 km. In different colors we see the different cells, we can notice than the most problematic zone will be the center of the scenario where more handovers will be produced; also we have the 6 BS and some MS, we have to remember that in total 112 MS will be created and will start to move around the scenario.

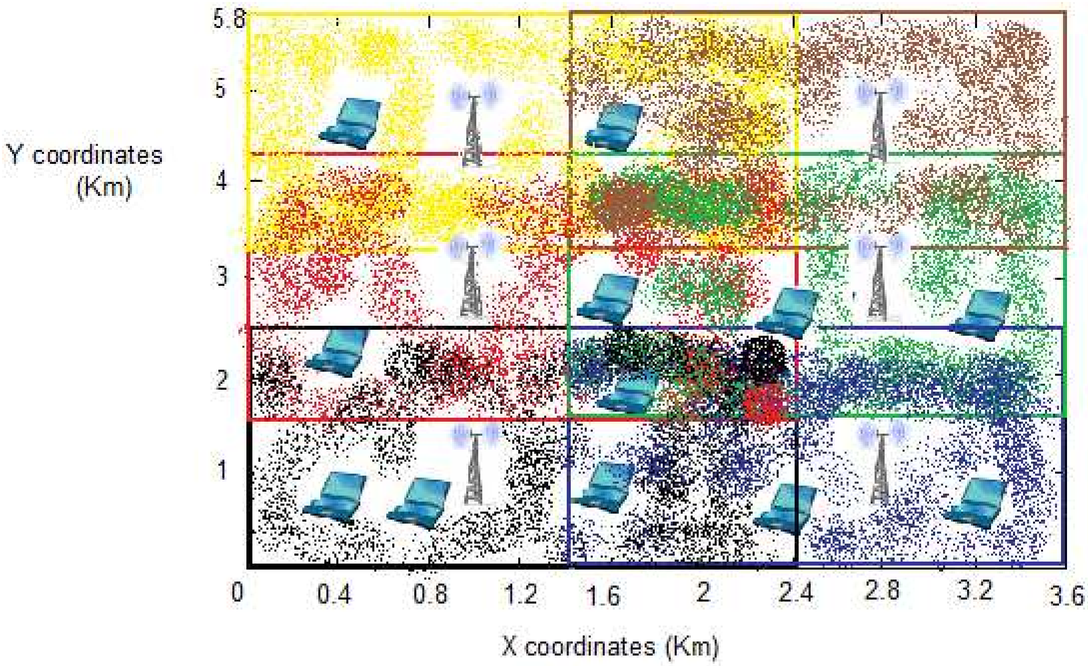

Fig12. Scenario representation

5.2 Mobility model

After creating all the mobiles, we are going to analyze how movement is done. We have chosen one of the most common mobility models and at the same time easier to implement, Random Waypoint model (RWP). Figure 13 will show us how one of the mobile will move. Each P represents one destination, when it arrives to one destination, a new destination is created.

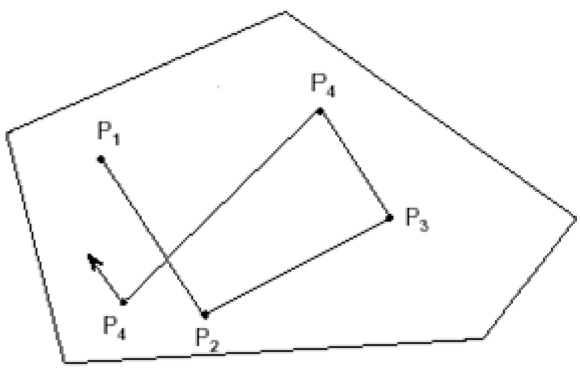

Fig13. RWP movement model, reference [16]

Each mobile has one destination to go, this destination is created randomly. When it has the destination, the mobile calculates the angle necessary to go there as fast as possible, after this the mobile moves to that direction. When it arrives calculates a new destination and the process starts again.

To make the simulation more real, there are three different speeds. One possibility is that the mobile goes on foot; we considered a speed of 4 kmph. The other two possibilities are when the mobile goes with some type of vehicle; we have considered two possible speeds, 50 and 80 kmph.

Having the speed and considering that in every iteration the algorithm will be a part of time, we can calculate the distance that the mobile does after an amount of time. With some trigonometry formulas, we can calculate the variation in the row and column. With this we can represent the scenario again with the variation, repeating this several times and using Matlab functions we can obtain a representation of the movement of each mobile.

As it can be imagined, we are imagining, we are supposing that the mobiles only moves inside the macrocell defined before. We do not simulate that the mobiles move out of the position simulated or that after the initial situation of the different mobiles no more mobiles are created. On the other hand mobiles that loose the connection with the base station and could not do the handover to a new base station will be also represented, but it will not move.

5.3 Mobile parameters

When the mobile is created, some characteristics are saved; also in the algorithm more characteristics are created. We are going to analyze them:

- Name: name of the mobile, is a American Standard Code for Information Interchange (ASCII) character, the return is the number of the ASCII character
- X axes position: the x axis where is the mobile situated
- Y axes position: the y axis where is the mobile situated
- Base station: the base station that the mobile is connected to
- SNR: the signal-noise ratio of the mobile station
- X axis destination: the x axe where the destination is located
- Y axis destination: the y axe where the destination is located
- Speed: is the speed of the mobile expressed in kilometers per hour
- Distance: the remaining distance between the position of the mobile and the destination, it is expressed in kilometers
- Angle: angle of the trajectory that the mobile must follow in order to arrive to its destination

- Missed call: this parameter is always no, ‘N’, when the mobile cannot continue with the connection this turns yes, ‘Y’, and the algorithm will do nothing with this mobile. Then will be added a drop call to the counter of drop calls.
- Arrived: when the mobile is moving to the destination the parameter returns a ‘N’, no; when it arrives it changes to ‘Y’, yes, in order to find a new destination
- Decide: this parameter appears when the loop starts; it is related with the handover decision. Three possible returns: ‘Y’, yes, where the handover is necessary immediately; ‘N’, no, where it is not necessary a handover; and the last one only appears in the fuzzy logic case, ‘P’, possible, that looks if it is a better option to change, but it is not necessary. In our case it will also look if the pretended channel is very busy or not to make the change

The idea of the algorithm is to measure the number of drop calls after some time. For this we have a counter that increase one when a mobile changes his characteristic of missed call to a ‘Y’. This happens when the SNR received is lower than six dB. Before this SNR no modulation is possible and the MS cannot work.

Other parameters to consider are the number of channel occupied for each base. When the mobiles are created we increase the number of channels of the base which it connects. The handover algorithm refreshes the number of channels when a mobile changes the base, also when a mobile loose the communication the number of channels of the base which was associated with gets decreased.

5.4 Other mobile parameters

For that simulation we only took one frequency band and one bandwidth, the important aspect of that project is to analyze the improvement that fuzzy logic gives if we compare it with the old algorithm to take the solution.

We have chosen the bandwidth between 3.6 and 3.8 GHz, with a bandwidth per channel of 10 MHz. As it can be imagined we have a band of 200 MHz, with the bandwidth of each channel we have an amount of twenty available channels per base. This configuration gives us an OFDM FFT size of 1024 subcarriers. Table 2 shows us the data rate of physical layer for our configuration with the bandwidth selected:

Modulation, coding rate	Data rate(Mbps)	
	DL	UL
QPSK, ½	2,520	653
QPSK, ¾	3,780	979
16QAM, ½	5,040	1,306
16QAM, ¾	7,560	1,958
64QAM,1/2	7,560	1,958
64QAM, ¾	11,340	2,938

Table2. Relation between modulation and data rate per channel [7]

We also need some physical and power characteristics of each BS and MS in order to calculate the SNR. We took the needed data for the simulation from some data given in reference [7].

To calculate the SNR we need to know the power received by the mobile station and the noise; one of the most important things is the power lost because of propagation, this aspect will be analyzed in the next part. The other data to consider are:

- Noise: to calculate the noise, we have to take the formula of white noise, the only data we need is the bandwidth, that we chosen before. After this we also have to add the noise figure; that according to the book is eight dB. Expression 2 explains us the formula. With all the data we found that we have a noise of -96 dBm.

  $$N = -174 + 10 \log B + NF \qquad (2)$$

  - B: Bandwidth (Hz)
  - NF: Noise figure (dB)
- Power of BS: the BS transmits a power of 43 dBm and it has an amplifier circuit with a gain of 15 dBi. The height of the antenna is 40 meters, that data is necessary for the propagation model
- Power of the MS: the most important thing of the mobile is to know that there is not internal gain in the circuit and, the circuits create 2 dB of losses. That mobile we will consider that is in a height of 1.5 meters.

After knowing the SNR, the mobile can decide which modulation and code rate use. The mobile will always take the best option of the modulation and code rate; this is because as better is this aspect as better it will be the data rate per channel. This is quite important in order to satisfy the quality of service in some applications, because VoIP only need 0.25 Mbps, but the other two applications of 'triple play', high speed internet and high-definition TV, need a minimum of 1 Mbps but it can arrive to high rates in order to have a better quality and speed.

5.5 Propagation model

We have to be very carefully in order to get a model that gives us what we need, a model dependant on the distance. One of our biggest problems was the frequency chosen; that is quite high for mobile telecommunications. Our decision is to use Hata propagation model for urban areas; although this model is for a maximum frequency of 2 GHz, according to the reference [17] is also valid for our frequencies.

The Hata Model for Urban Areas, also known as the Okumura-Hata model for being a developed version of the Okumura Model, is the most widely used radio frequency propagation model, for predicting the behavior of cellular transmissions in built up areas. This model incorporates the graphical information from Okumura model and develops it further to realize the effects of diffraction, reflection and scattering caused by city structures. This model also has two more varieties for transmission in Suburban Areas and Open Areas.

Hata Model predicts the total path loss along a link of terrestrial microwave or other type of cellular communications. Hata model for urban areas is formulated as it is shown in expression 3:

$$L_U = 46.3 + 33 \log f - 13.82 \log h_B - C_H + [44.9 - 6.55 \log h_B] \log d \ (dB) \quad (3)$$

Where C_H is in our case $3.2 (\log (11.75\, h_M))^2 - 4.97$

- f: frequency (MHz)
- h_B: height of the base station (meters), in our case 40 m
- h_M: height of the mobile station (meters), in our case 1.5 m
- d: distance between the mobile station and the base station that is connected with (km)

Having all the parameters and the propagation model we have a formula that relates the SNR with the distance. After this we calculate the distance between the position of the mobile and the base station which is connected with in order to get the SNR. Expression 4 gives us the formula used to calculate the SNR of each mobile

$$SNR = 10.9 - 34 \log d \ (dB) \quad (4)$$

5.6 Fuzzy logic algorithm

To evaluate more accurately the advantages of the fuzzy logic, we have included two inputs, with that imputes and some predefined rules we have an output with three possible options. First we will analyze the inputs, then the rules and finally the output.

First input to consider is the same that is used in the old way to make the decision, the SNR. But this time it is not a threshold, now we use three triangular shapes n order to decide the quality of the SNR.

In order to make a decision we have looked the different modulations that support matlab and the amount of SNR needed to support high speed applications, so the number when the triangular shapes start does not follow a formula, it follows modulation and application needs. Figure 14 shows us the graphic of the input SNR. As we can see we have three levels, when we work with the less powerful modulation, QPSK, we will work below 11 dB of SNR; 16 QAM is considered the medium SNR being between 9 and 22 dB; and high modulation, 64 QAM, is considered from 20 to the maximum:

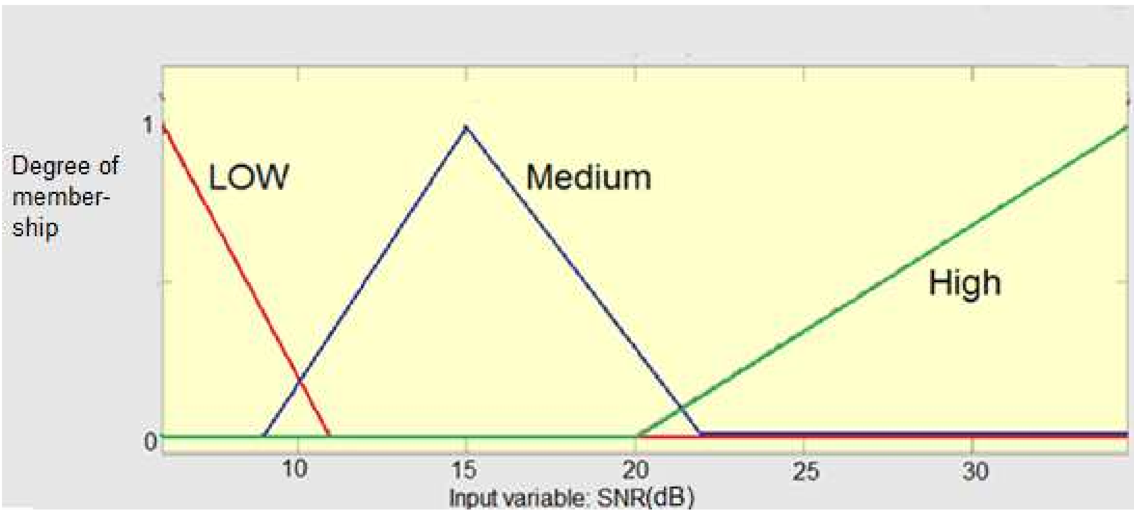

Fig14. Fuzzy logic input SNR

So we can see that the majority of the surface of the three levels is working in the different modulations. In order to put a limit we decided that 34.6 is a good limit.

The second input to consider is the number of channels. As we explained before, each base has a maximum number of channels, so it is good that if the current base is very busy, if it is possible make a handover in order to release one channel. The decision has been taken thinking on the channels occupied and the need of channels by the other mobiles, so again the points has been chosen following the needs of the system. Figure 15 shows us the graphic of the input number of channels. Here the low is referred to the occupation, it is until 8 channels, which corresponds a low use of the channels available in the base station, medium is between 2 and 18; but it dominates the region between 6 and 15 channels, when the BS starts to be busy but it can still accept more MS and high between 12 and 20, but it dominates from 15 to the end, when only MS that really need of making a HO because of the danger of losing the connection are accepted.:

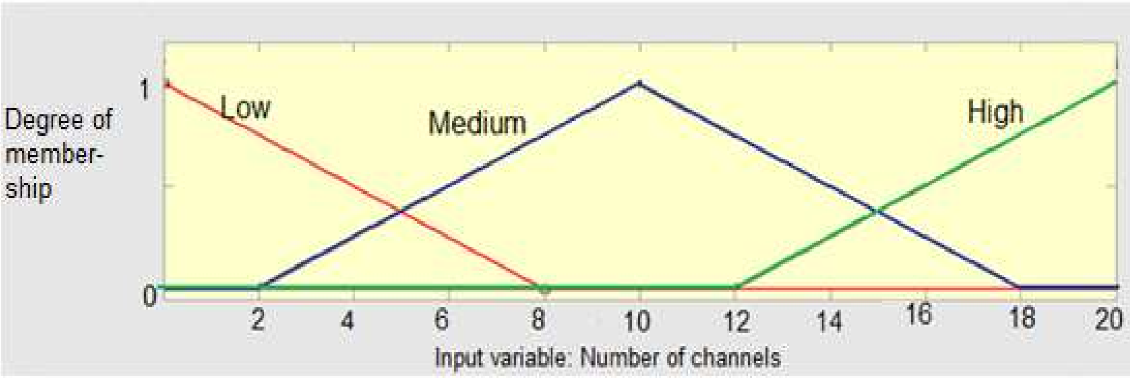

Fig15. Fuzzy Logic input, number of channels

As we said before the maximum numbers of channels that are allowed in our configuration are twenty channels, it is important to try to change before one base arrives to that number of channels; the bases situated in the middle are the ones which will probably be more occupied.

First we will see the graphic of the outputs and with this we will explain the rules IF-THEN that take us to that outputs. The output woks a little bit special, we have selected a range between 0 and 90, that is not the important point, because you can modify it as you want; the main think is how to work it, and where to put the starting and ending points of each shape. The program evaluates which is the position on the output according on the rules defined, which combined with the inputs gives us a number, which we evaluate with the output figure. Figure 16 shows us the graphic of the output of HO. The output gives us three options for the handover decision. First one is ‘N’, which means no, the second one is the biggest, in order to give more flexibility to the algorithm, is called ‘P’, and it means possible, we will explain it later the meaning. Last one is ‘Y’, and it means yes:

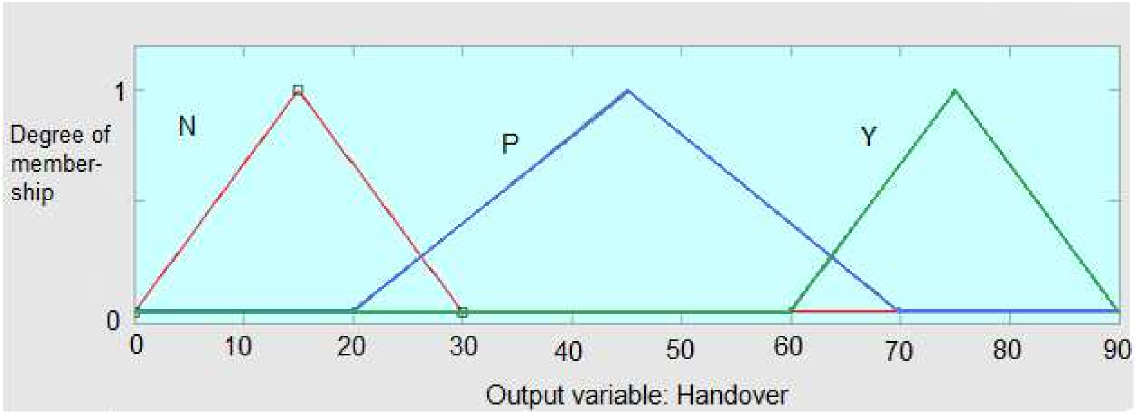

Fig16. Fuzzy logic output Handover decision

Having the inputs and the outputs, we have to define some rules that match that inputs and outputs. From expressions 5 to 11 we have the different rules use in the fuzzy logic algorithm:

- *IF SNR is low THEN handover is 'Y'* (5)
- *IF SNR is medium and Channels are low THEN handover is 'N'* (6)
- *IF SNR is medium and Channels are medium THEN handover is 'P'* (7)
- *IF SNR is medium and Channels are high THEN handover is 'P'* (8)
- *IF SNR is high and Channels are low THEN handover is 'N'* (9)
- *IF SNR is high and Channels are medium THEN handover is 'N'* (10)
- *IF SNR is high and Channels are high THEN handover is 'P'* (11)

After defining all, the algorithm of the decision receives the two inputs, with the rules, the algorithm returns a number which gives us the decision that has to be made. Then the rest of the algorithm evaluates if the handover can be done in case it is necessary.

As we can see the SNR is quite more important than the number of channels, this is logical because SNR is quite more important, and is the parameter than decides when the mobile loss the communication. We can see that when the SNR is high is when less possibilities of handover exist. The number of channels helps us to organize better the network and try to avoid future congestions.

So having all the parameters, we just need to realize the defuzzification. We have selected the max-min method because we have to be quite strict with our decisions. Matlab offers us the possibility of watching the surface of our fuzzy logic rules. We can notice that the numbers in the scale of handover are the ones we explained before in the figure 16 which the output and the three levels where defined. Figure 17 shows us that surface, in the figure we see the three possible decisions of HO, as we explained before; the evaluation of the two inputs with the rules gives us a number which corresponds to a decision in the output of the fuzzy logic algorithm. The yellow color corresponds to a decision of yes in HO; this corresponds as it says in the rules to a low level of SNR. In light blue we have the decision of possible HO; this corresponds when we have a middle level of SNR and middle occupation of the number channels, or when we have a high occupation of the number channels. The dark blue part corresponds to the decision of no HO; that corresponds to the best conditions in the scenario.

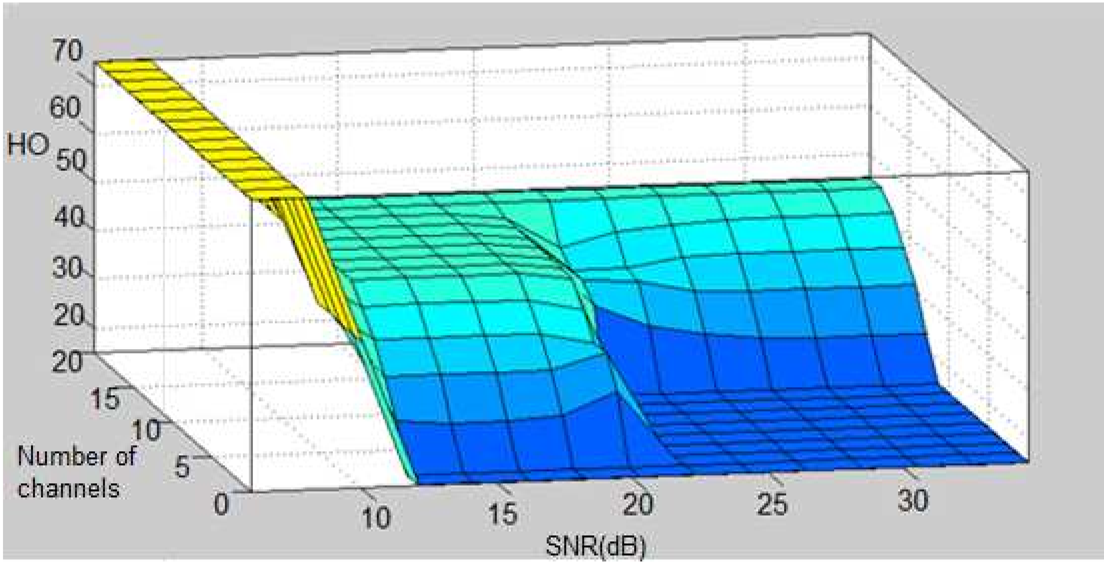

Fig17. Surface view of Fuzzy logic algorithm

5.7 Algorithm used

So, after knowing all the previous parameters we can completely explain how is the algorithm structured and how it works.

The main function creates the scenario using another function and creates the map. After enters in a double loop, the first part consists in each increment of time that the mobiles have to look about the handover. We thought that the increment of one second is quite good according to the different speeds that we have. The second part analyzes and realizes the algorithm with all the mobiles that have been created.

So inside this loop each mobile passes through an amount of functions, we are going to explain it all:

- First of all the loop check if the mobile is still connected, if the connection is lost the mobile does not enter into the loop

- Then the loop checks if the mobile has arrived to its destination in that case it calculates a new destination, calculating the row, the column, the distance, and the angle necessary in order to move properly.
- If the mobile has not arrived, then the mobile moves in the correct direction, after the movement, using trigonometric formulas calculates the new row and column that it occupies.
- Then the mobile calculates its SNR. Using Pythagoras equation, the distance between the actual position and the base which is connected with; having this and using the formula described before, according to the propagation model described we obtain the current SNR.
- If the SNR is lower than six dB, the mobile change his parameter missed call on ‘Y’. Then it increases the parameter drop calls, release the channel occupied and goes to the finish of the loop. This mobile will not enter any more in the loop.
- If the SNR is above six dB, the algorithm enters in the part of the handover decision. The algorithm only can enter in the fuzzy logic part, or the old part; so to compare the results we have to change it in each execution. The old decision we have put a threshold of six point five dB. Then we save the decision in a new parameter of the mobile structure.
- Having the decision we have to enter in the handover algorithm. This algorithm is quite basic because the main goal of this simulation is to analyze the benefits of using fuzzy logic instead of the classical way to decide if the handover is necessary or not. So if the decision is ‘N’ the algorithm as it can be predictable does nothing. If the decision is ‘P’, the handover looks first the number of channels, if it is less than fifteen then looks the distance to the nearer base, because with less distance the SNR is higher, so maybe the number of channels is ok but we are losing quality of service it is better to maintain that base. If the decision is ‘Y’ just checks if there is a channel available, if there is makes the handover procedure.
- After all this, the algorithm saves the current position, in this part it enters even the call is finished, this is in order to represent it.
- After the first loop, the algorithm takes a frame of the representation of all the mobiles, this we will do it with a little simulation, the big simulations we need in order to get some results to analyze
- Finally, the algorithm represents all the frames obtained, with this we saw all the movement made by the mobiles. Then it appears a graphic representing the drop calls in relation with the time.

In figure 18 we can see a diagram explaining how the algorithm works for each mobile. With this algorithm we think we will get a real approximation about what in which measure the fuzzy logic will benefit to the handover procedure. We have to remember that introduce fuzzy logic in a system is quite simple and fast to implement, so it is not a big problem that will make the handover procedure worse. This algorithm is thought for the case that the mobile station is who makes the decision about making or not the handover:

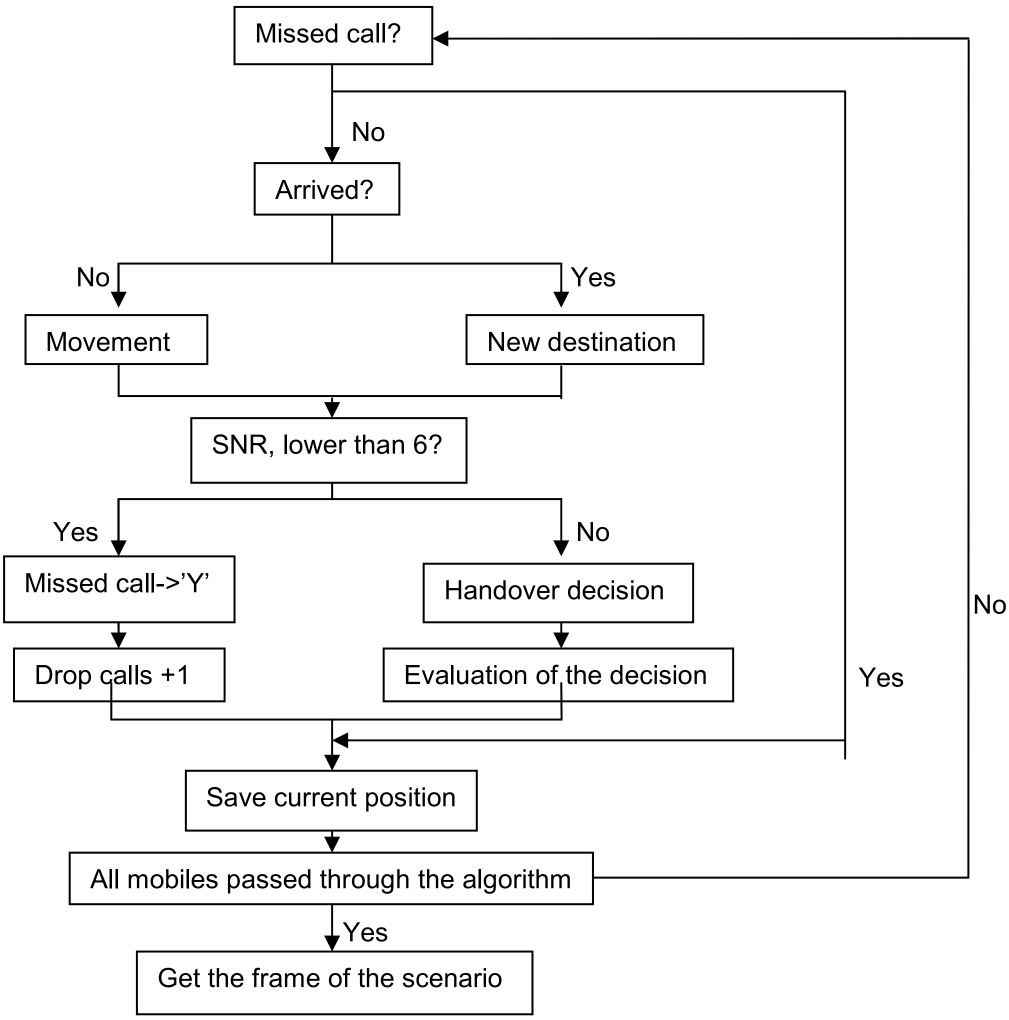

Fig18. Algorithm steps for each mobile

5.8 Summarize of simulation features

We will summarize main aspects of the simulation in the table 3:

Number of mobiles created	112
Number of bases	6
Frequency (GHz)	3.6-3.8
Speed of each mobile (Kmph)	4, 50 or 80

Bandwidth of each channel (MHz)	10
Maximum number of channels per base	20
Area of the scenario (km)	3.6 per 5.8
Propagation model	Hata
Mobility model	RWP

Table3. Features of the simulation

6. Simulation results

After the explanation of all the WiMAX technology and made the explanation of the algorithm, it is time to check the results. All the simulations are done with the same time of modulation, what it means the same amount of movements. Figure 19 shows us the results:

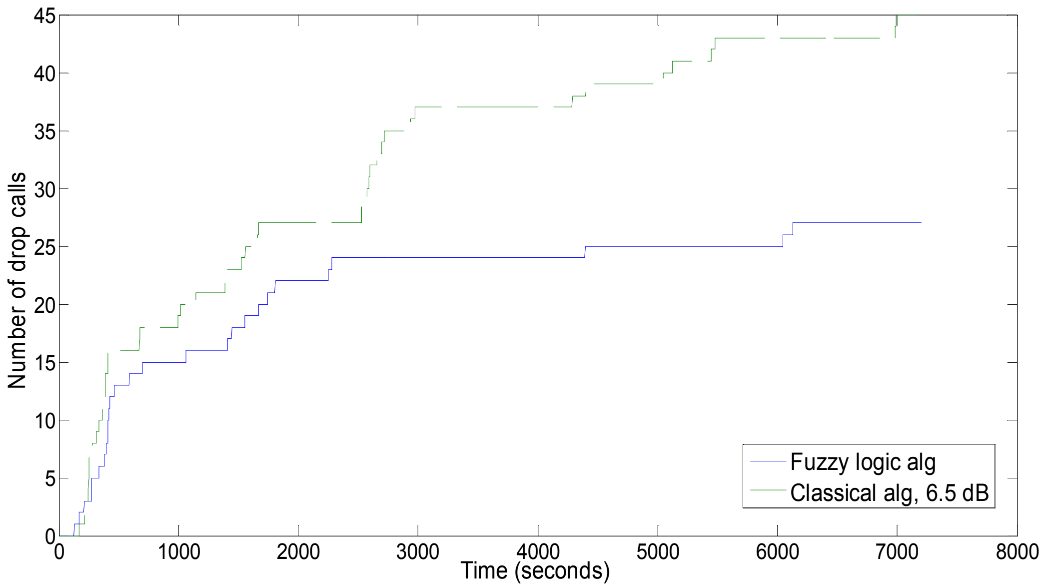

Fig19. Number of drop calls, frequency of 3.6 GHz, different speeds, threshold of 6.5 dB, 112 mobiles

In first results we can observe easily that the fuzzy logic algorithm gives us better results than classical algorithm. We are talking of 18 more drop calls in classical algorithm. According that we have 112 mobiles created, we are talking of an improvement of 15% in the number of drop calls. To evaluate better the benefit of using fuzzy logic algorithm we will change some aspects of the simulation and evaluate the results. First of all we will see what happens if we change the threshold of the classical algorithm, see if a different threshold gives us better results than fuzzy logic algorithm. Figure 20 shows as the graphics with different thresholds.

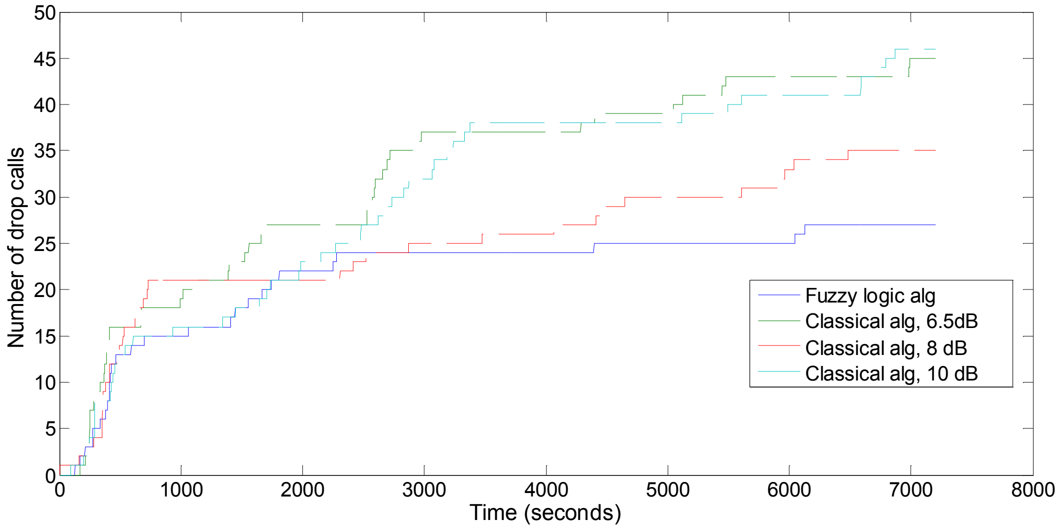

Fig20. Number of drop calls; frequency of 3.6 GHz; different speeds; threshold of 6.5 dB, 8 dB and 10 dB, 112 mobiles

As it is shown in the figure, a threshold of 8dB gives us better results than the initial threshold, but is not better than the fuzzy logic algorithm. We have 8 more drop calls in classical algorithm with this threshold than in the fuzzy logic algorithm. It is a 7% less of drop calls. The difference with the threshold of 10 dB is a 16 % more of drop calls.

Other option to change is the number of mobiles, shown in figure 21, if we consider that it can also be used in a semi-urban area or rural area, it is good to simulate that conditions and see the results, and for this we will create 76 mobiles:

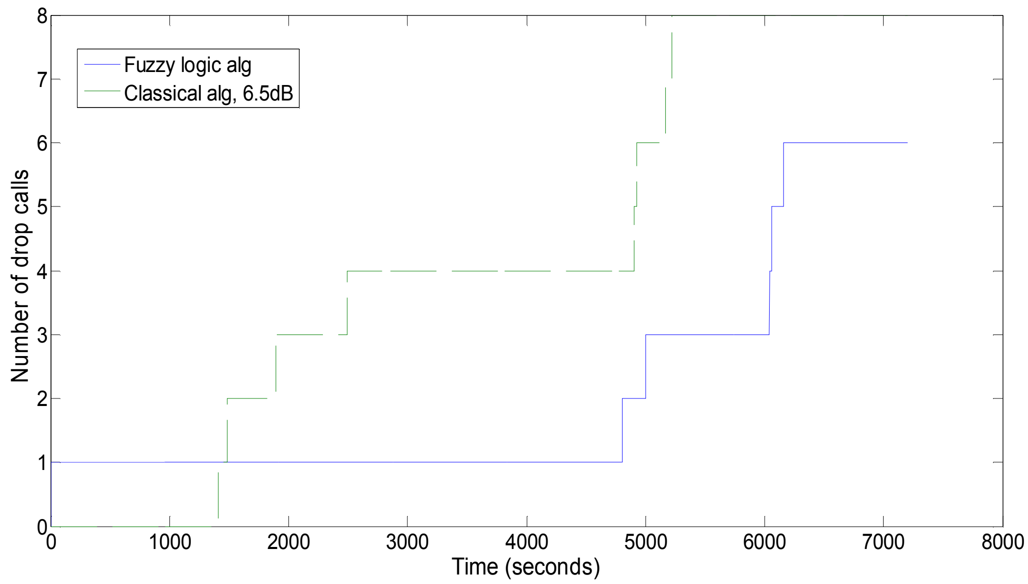

Fig21. Number of drop calls, frequency of 3.6 GHz, different speeds, threshold of 6.5 dB, 76 mobiles

Obviously the difference is lower and the number of drop calls for both algorithms have decreased in a big number, this is logical because the BS has a higher number of free channels. But also with a lower number of mobiles the fuzzy logic algorithm has a better behavior. Classical algorithm has 2 more drop calls than fuzzy logic algorithm, which represents a 3% more of drop calls. Finally we will change the frequency that is working with all the mobiles, restoring first the urban conditions. We change to another band, 2.4-2.6 GHz, maintaining the bandwidth. We expect to have less drop calls, because as we seen in expression 1, the losses caused by the propagation model are dependant of the frequency, so if we decrease that feature, looses will be less and the SNR higher. Figure 22 shows us the results:

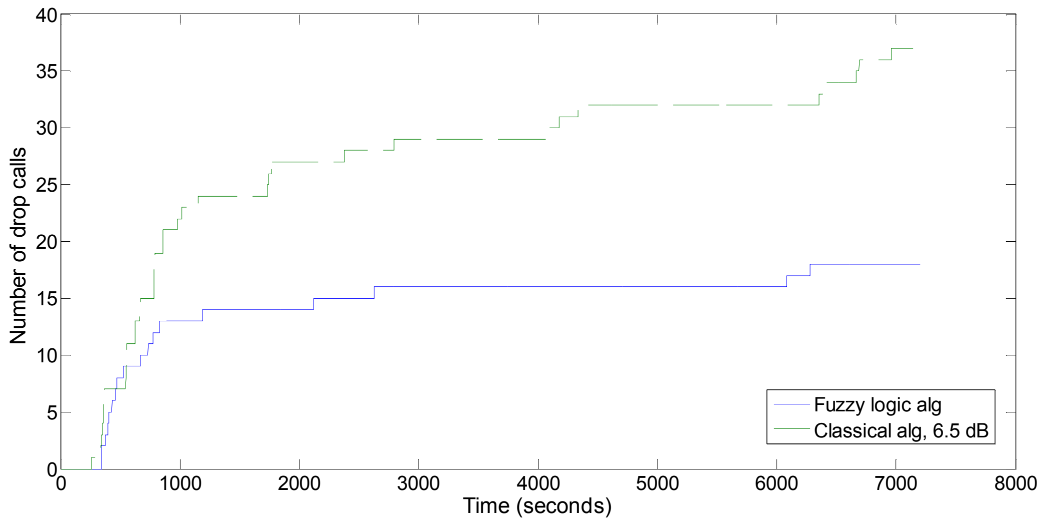

Fig22. Number of drop calls, frequency of 2.5 GHz, different speeds, threshold of 6.5 dB, 112 mobiles

As it was expected, the number of drop calls has decreased; but the difference of drop calls is higher. With classical algorithm we have 19 more drop calls, what means a 16% more of drop calls. Now we will change the speed of the mobiles. At the beginning we have three different speeds, now we are going to evaluate the number of drop calls in two cases, first if the speed is the fewest possible, 4kmph, simulating that all MS are moving on foot. Then we are going to simulate with 80 kmph, as if all the MS are going by some kind of vehicle. Figure 23 and 24 shows us the results:

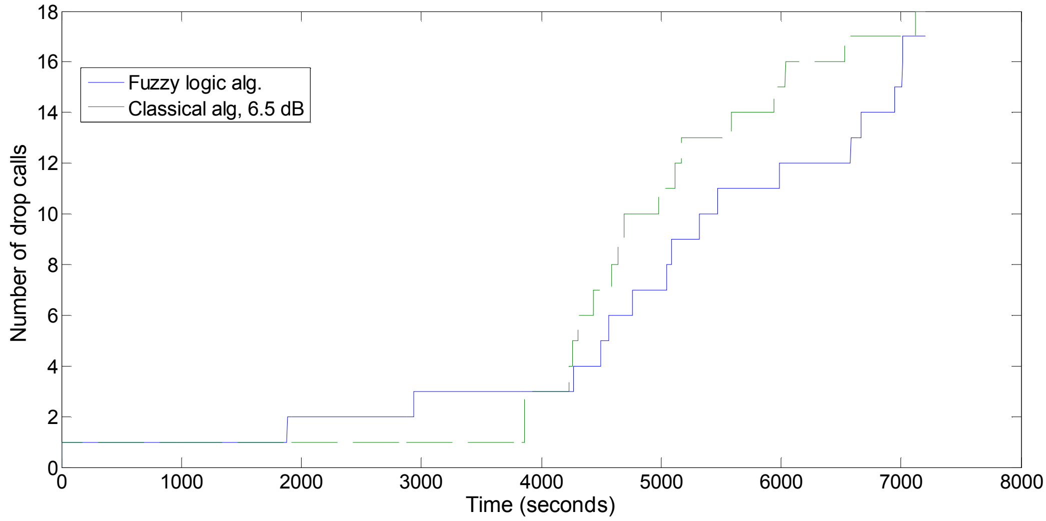

Fig23. Number of drop calls, frequency of 3.6 GHz, 4kmph, threshold of 6.5 dB, 112 mobiles

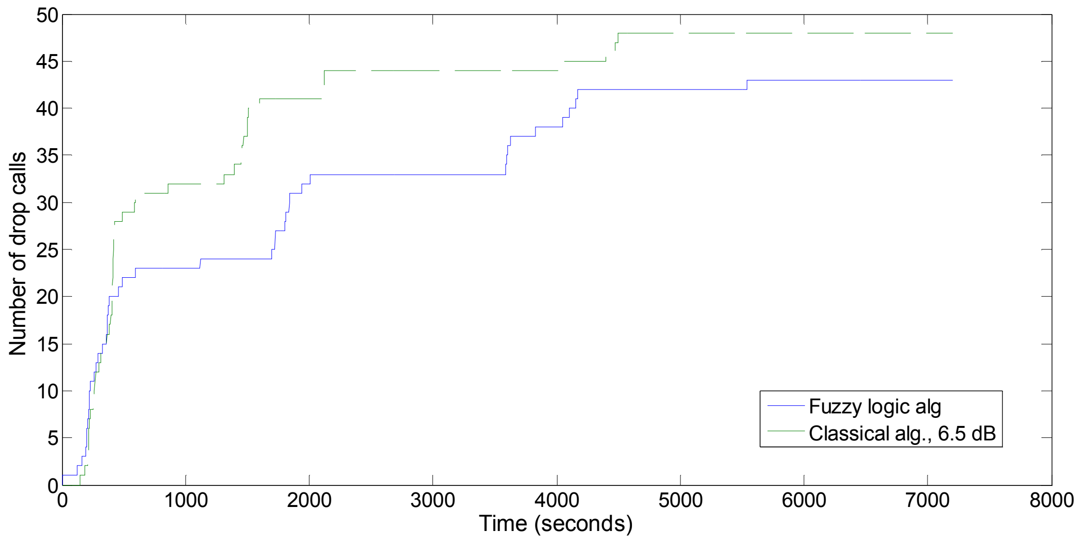

Fig24. Number of drop calls, frequency of 3.6 GHz, 80kmph, threshold of 6.5 dB, 112 mobiles

As we can see the differences are less compared with the different speeds. As it was predictable in the graphic of 4 kmph, the number of drop calls has decreased because the mobiles has not moved the same distance, on the other hand, with the highest speed the number of drop calls has increased. The highest speed graphic has seen how the fuzzy logic algorithm graphic has increased much more than the other, but as it can be seen, on the classical algorithm, the number of drop calls has been increased quite soon compared with the fuzzy logic one. The difference in 4 kmph is just 1 % better for fuzzy logic; in the 80 kmph graphic is 4 % better.

Now we are going to change the limits of the fuzzy logic inputs, and see how this affects to the graphic. We will do it less relaxed, stricter. In the SNR input, the low level arrives until 10 dB, and the high level starts in 21 dB. In the number of channels we changed the medium level of number of channels, which is between 6 and 14 channels. Figure 25 shows us the graphic:

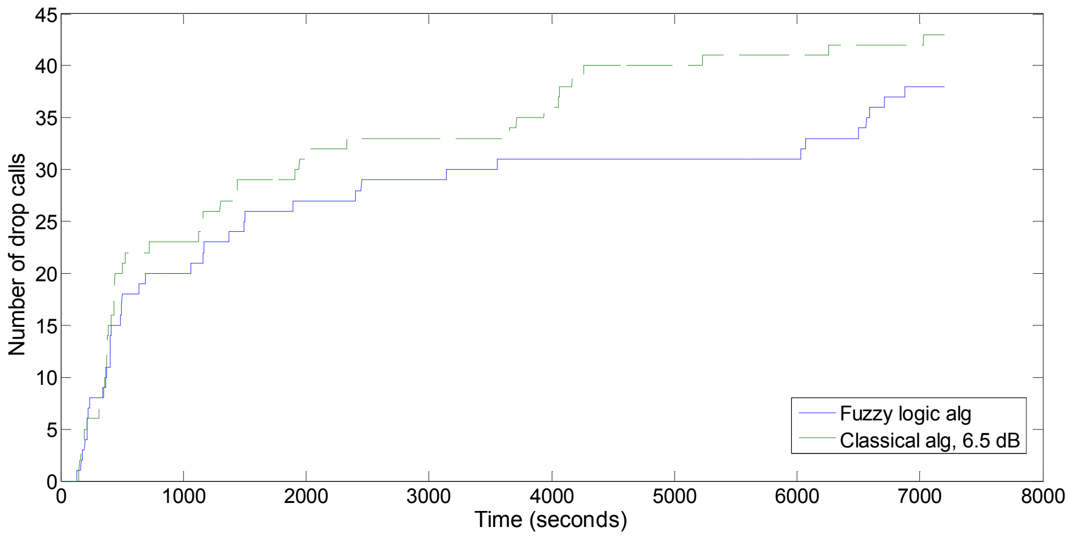

Fig25. Number of drop calls, frequency of 3.6 GHz, different speeds, threshold of 6.5 dB, 112 mobiles, new fuzzy logic

As it was expected, the fuzzy logic graphic is worse. But making more relaxed than it was at the beginning, we can produce unnecessary handovers. The difference in this graphic is 6%. Finally, in figure 26 we will study the number of handovers done in the scenario related with the number of mobiles.

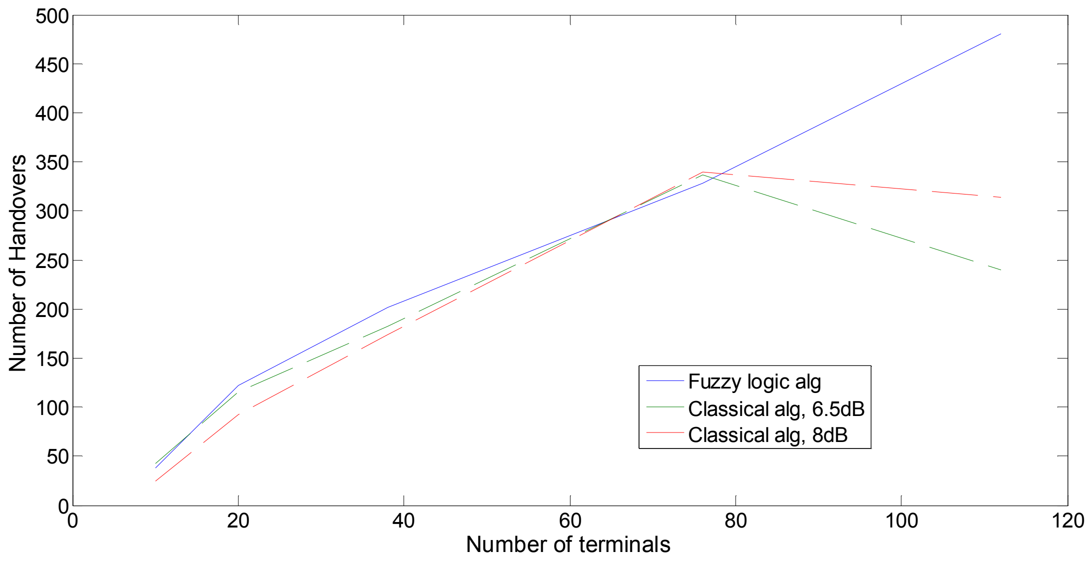

Fig26. Number of handovers according to different number of mobiles, frequency 3.6 GHz, thresholds 6.5 dB, 8 dB, different speeds.

This graphic gives us one of the disadvantages of fuzzy logic. In almost all the different number of terminals, we have a higher number of handovers in fuzzy logic algorithm. Another important fact of the figure 26 is how in the classical algorithms, in the highest number of terminals, the number of handovers is decreasing. This has the explanation in all the study we made previously of the drop calls, as we saw in figure 20, classical algorithm has higher drop calls, and sooner so the number of mobiles decrease quite fast, probably faster than with the distribution of 76 mobiles, so we have a higher number of handovers previously. This difference is higher in the threshold of 6.5 dB, where we have a higher number of drop calls.

On the other hand, n fuzzy logic algorithm, because different base stations can handle better the mobiles, the number of handovers does not decrease; and it is continuously increasing. So, according to the graphic, fuzzy logic makes more, or the same depending the threshold, handovers with low number of mobiles, with a medium number of mobiles, the number remains the same, but in higher number of mobiles is much bigger, because is able to maintain more calls.

We will resume the results of the simulation in table 4:

Difference of number of drop calls	**Percentage (%)**
Algorithm in normal conditions	15
Difference with threshold of 8 dB	7
Difference with threshold of 10 dB	16

Difference in a lower number of mobiles	3
Difference in a lower frequency	16
Difference with a speed of 4 kmph	1
Difference with a speed of 80 kmph	4
Difference with the new fuzzy logic algorithm	5
Difference of handovers between FL and 6.5dB for 10 terminals	5 HO more in classical
Difference of handovers between FL and 8dB for 10 terminals	14 HO more in FL
Difference of handovers between FL and 6.5dB for 20 terminals	7 HO more in FL
Difference of handovers between FL and 8dB for 20 terminals	30 HO more in FL
Difference of handovers between FL and 6.5dB for 38 terminals	20 HO more in FL
Difference of handovers between FL and 8dB for 38 terminals	28 HO more in FL
Difference of handovers between FL and 6.5dB for 76 terminals	9 HO more in classical
Difference of handovers between FL and 8dB for 76 terminals	12 HO more in classical
Difference of handovers between FL and 6.5dB for 112 terminals	240 HO more in FL
Difference of handovers between FL and 8dB for 112 terminals	166 HO more in FL

Table 4: Simulation results in percentage

7. Conclusion

After all the simulations and having analyzed the results with the different amount of times, is time to answer the most important question, does fuzzy logic give any benefit to the handover algorithm of mobile WiMAX? Yes.

We have simulated the algorithm in different conditions and we have achieved always better results. According to the results, in an urban scenario the number of drop calls is between 1 and 16 per cent less in fuzzy logic algorithm.

In a less populated scenario, the results are just 3 % better for fuzzy logic algorithm. But according we just had a little benefit, and how easy is to implement fuzzy logic in the hardware is quite recommended to install it in all the devices. Also changing the fuzzy logic algorithm or putting a fixed speed, the behavior of fuzzy logic is better than the classical algorithm.

The main disadvantage, remains in the fact that we have more handovers using fuzzy logic with low number of mobile stations, with higher we explained before that it is because the number of drop calls is quite higher using fuzzy logic algorithm. This will finish in more power needed, but the results are quite better to use fuzzy logic and try to improve the power saving techniques, fuzzy logic can be also a good option.

So in order to develop Mobile WiMAX to make the mobile WiMAX the future standard of mobile communications, fuzzy logic has to be considered in order to make more robust one of the weakest points of the Mobile WiMAX, the handover procedure. Also it can be proved to regulate the power control of mobile WiMAX and to prove with other communication systems. Fuzzy logic has demonstrated to be a powerful tool in other fields of live and also will be a tool to be considered in communication systems.

Considering that we have simulated a very crowded urban area, with a few antennas, we have also seen that the results are much better, what will mean a few number of antennas to be installed, this means less money to spend by the companies in order to develop mobile WiMAX.

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9. Abbreviations

AAS	Advanced Antenna System
AES	Advanced Encryption Standard
AMC	Adaptive Modulation and Coding
ARQ	Automatic Retransmission Requests
ASCII	American Standard Code for Information Interchange
ASN	Application Service Network
ATM	Asynchronous Transfer Mode
BS	Base Station
CSN	Connectivity Service Network
DL	Down Link
EAP	Extensible Authentication Protocol
ETSI HIPERMAN	European Telecommunications Standards Institute High Performance Radio Metropolitan Area Network
FBSS	Fast Base Station Switching
FEC	Forward Error Corrections
FDD	Frequency Division Duplexing
FFT	Fast Fourier Transform
FL	Fuzzy Logic
GHz	Gigahertz
HARQ	Hybrid Automatic Retransmission Requests
HHO	Hard Handover
IEEE	Institute of Electrical and Electronics Engineers
IFFT	Inverse Fast Fourier Transform

IP	Internet Protocol
Kmph	kilometers per hour
LDPC	Low-Density Parity-Check
MAC	Media Access Control
MDHO	Macro Diversity Handover
MPDUs	MAC Protocol Data Units
MHz	Megahertz
MS	Mobile Station
NAP	Network Application Provider
NLOS	Non-Line-Of-Sight
NSP	Network Service Providers
OFDM	Orthogonal Frequency Duplexing Mode
OFDMA	Orthogonal Frequency Duplexing Mode Access
OSI	Open System Interconnection
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase-Shift Keying
RF	Radio Frequency
RSSI	Received Signal Strength Indicator
RWP	Random Waypoint model
SFID	Service Flow Identifier
SINR	Signal-to-Interference-plus Noise Ratio
SNR	Signal-Noise Ratio
TDD	Time Division Duplexing

UGS	Unsolicited Grant Service
UL	Up Link
VoIP	Voice over Internet Protocol
WMAN	Wireless Metropolitan Access Networking
WiMAX	Worldwide Interoperability for Microwave Access