QoS: From Wi-Fi to WiMAX

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***Abstract*— A number of years ago, the world of computer networking have witnessed an explosive evolution which continues to rise. In this evolution, the multiple technologies found themselves attracted in an increasingly strong gravity field, generated by the shining star in the computer universe that is known as the "Internet". Cognitive Radio (CR) is emerging as one of the key technologies to solve the problem of spectrum scarcity faced by current wireless systems. They are being helplessly directed to a common center, consequently facing a crossroad illustrated by the convergence of numerous networking solutions that have been yet considered mutually exclusives. In our work, we try to approach the problematic related to the optimization of the convergence of two very promising wireless networking technologies which are Wi-Fi and WiMAX. We propose the example of a practical configuration where the two networks converge in a complementary and constructive structure rather than a competitive one. Thus, our contribution is summed in the proposition of a coupling strategy between the access controls in the two networks in the aim of enhancing the global quality of service management in the new composite network. We propose the implementation of that strategy in the form of a combined admission control algorithm that is implemented and verified through simulation, using the specialized free open source software "NS-3".**

Keywords- Wi-Fi-WiMAX convergence, QoS management, Wireless LAN, Wireless MAN, Media access control, NS-3 simulation, cognitive radio.

I. INTRODUCTION

It is a general agreement that future networks will include different network technologies and services under a single infrastructure intended to represent the next generation network NGN (Next Generation Network) [1]. Barriers that formerly separated different types of communication networks are beginning to fall one after the other and access terminals become multi-media and multi-service; hence integrating several communication interfaces to connect to different networks.

A Cognitive Radio network aims to support highly reconfigurable devices that are capable of sensing the current environment, and adapting the transmission parameters to the specific scenarios, also based on the Quality of Service (QoS) requirements of the applications.

In this work, we tackle the issue of convergence and collaboration of two widely spread wireless networks having both known undisputed success: Wi-Fi and WiMAX. We will focus mainly on the aspect of QoS (Quality of Service) of this convergence which is no more an abstract idea or a simple theme of research. We can already find on the market devices that simultaneously integrate Wi-Fi and WiMAX interfaces.

The main question that will guide our work is «How to get the most benefit of the association between WI-FI with its free easy aspects on one side and WiMAX with its long range and high mobility on the other?». So we'll propose a scenario of collaboration between the two networks taking into account the economic reality. Therefore, we will consider the case where a Wi-Fi network is assumed to be already existing, and where one would add a WiMAX network in a collaborative architecture. The two networks are thus linked with a centralized QoS management. Our goal is to provide a constructive coupling strategy that will guide the centralized management in the decision to admit or not a stream of data within one of the two networks.

The remainder of this paper is organized as following. Section II gives a background about QoS implementation and management in the concerned wireless networks. Section III describes a state of the art with regards to network convergence. Section IV presents the simulation and results accompanied by a discussion. Finally, the paper is concluded in Section V.

II. BACKGROUND

In practice, several different network technologies will coexist and grow in the future to meet the emerging demands in terms of bandwidth and capacity. It is very likely that a combination of different radio systems will be used simultaneously to meet the capacity requirements [2].

A. The CME (composite radio environment) Framework

In such a mixed radio environment as the one previously mentioned, *Reconfigurability* is a key element which allows terminals and the dynamic elements of the network to select and adapt to the most appropriate access radio technology in accordance with the conditions encountered in particular parts of the service coverage area and at certain times of the day. Nowadays, a multitude of standards of RAT (Radio Access Technology) are used in wireless communications [3]. Users are thus directed to the network and the most appropriate radio technology depending on the criteria of the user profile and the performance of the network. Therefore, different RATs are used in a complementary rather than competing manner.

B. *Qos Management in Wi-Fi Networks*

The mechanisms of media access present in the original IEEE 802.11 standard do not guarantee QoS. However the introduction of the IEEE 802.11e standard proposed additional media access mechanisms for QoS support. However, these are not sufficient to ensure QoS, hence the necessity to propose additional algorithms for resources allocation and the control of admission of stations (or streams) in the network.

However, unlike wired networks, in wireless networks a station has no knowledge of the availability of network resources and cannot make specific decisions of whether to admit or deny new workflow. In addition, with the contention based channel access mechanism for CSMA/CA, the allocation of bandwidth is almost impossible, which leads to a soft guarantee of QoS. Because of these two major difficulties, admission control, and the reservation of bandwidth in IEEE 802.11 wireless networks is somewhat difficult [4].

HCF (Hybrid Coordination Function) was introduced to support applications that have QoS requirements. It has two main mechanisms:

- A new contention-oriented method called EDCA (Enhanced Distributed Channel Access) which is the extension of the legacy DCF (Distributed Coordination Function) method.
- An access method without contention called HCCA (HCF Controlled Channel Access).

In the EDCA, QoS is supported by introducing four Access Categories ACs with different priorities. Each of the ACs represents a DCF function with a different DIFS (Distributed Inter-Frame Space) period for each AC. The DISF term is replaced with AIFS (Arbitration Inter-Frame Space). HCCA function allocates TXOPs (Transmission Opportunities) periods for the wireless stations on a polling basis. These TXOPs are calculated according to the required QoS parameters. The TXOP is a key parameter introduced by the HCF. It represents the time interval during which a station can attempt to send frames. A TXOP can be obtained by winning an EDCA contention or can be simply attributed by the access point after HCCA polling.

Thus, the HCF introduces four queues at the MAC layer level corresponding to the four ACs and eight queues according to a finer legacy flow classification called TSs (traffic Streams). When a frame arrives at the MAC layer is marked by a TID traffic identifier (from 0 to 15) which also defines the priority according to the QoS parameters (see Table 1) [4].

The frames with a TID between 0 and 7 are classified in four ACs queues according to pre-established EDCA rules (see table 2.4). The QoS at the level of these four queues is supported on a priority basis, where the stream with more firm QoS parameters, has the higher priority. The differentiation of the ACs is made by the allocation of different time constants (AIFS, Cwmin –Minimum Contention Window- and Cwmax-Maximum Contention Window-) to the different ACs. Thus for ACi and ACj with $0 \le i \le j \le 3$ there would be CWmin [i] ≥ CWmin [j], CWmax [i] ≥ CWmax [j] and AIFS [i] ≥ AIFS [j]. Also, each EDCA priority level has a different Backoff function, assigning a shorter period to the highest priority. Thus the prioritized flow will have a better chance to access the media [5].

Frames with a TID between 8 and 15 are classified in eight rows of TSs according to pre-established HCCA rules. Here the QoS is supported on a strict basis according to the QoS requirements of a stream (maximum delay, tolerated loss of packages tolerated Jitter,... etc)

TABLE I. EXEMPLE OF TID CLASSIFICATION INTO AC

Priority	AC access category	Type of traffic
7	3	Channel 64 Kbps
6	3	Channel 64 Kbps
5	2	Video 1.5 Kbps
4	2	Video 1.5 Kbps
3	1	Survey Video
2	0	Best effort
1	0	Background
0	0	Background

C. • *QoS management in WiMAX networks*

Despite the fact that the original standard 802.16 for WiMAX already took into account the QoS support, communication admission control CAC and resource planning RP is still an open topic. Fig.1 represents the architecture of QoS management in WiMAX, with the dotted parts representing the functions not specified in the standard IEEE802.16 (left to the manufacturers) [6].

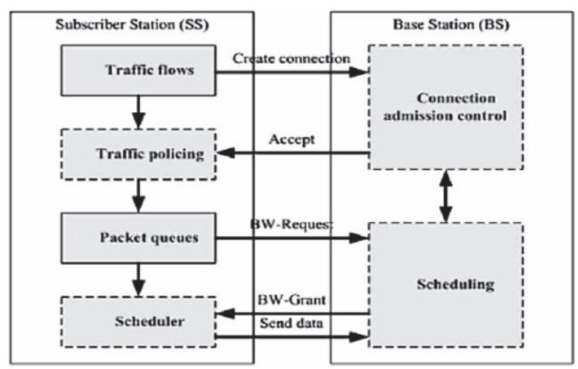

Figure 1. The architecture of QoS management in WiMAX [6].

Several solutions to the problem of the management of QoS in WiMAX are proposed in the literature [6, 7, 8]. Most of them focus on resource planning while few deal with the problem of CAC. This is seen somewhat as being unrealistic, knowing the fact that both mechanisms are necessary for any worthy QoS management system.

Generally, resource planning methods consist of a hierarchy of well-known classical schedulers, such as the EDF Scheduler (Earliest Deadline First) and the WFQ Scheduler (Weighted Fair Queuing). In these methods, the simplest solutions are favored to implement QoS management in real time (frame by frame). [6]

Resource planning consists of two procedures:

- The allocation of resources to the physical layer.
- The scheduling of the frames in the queues at the MAC layer.

These two procedures can be handled separately as it has often been the case, but they can be taken into account simultaneously in the so-called"Cross layer" solutions. The latter seem to attract more and more interest in the recent works.

CAC management typically uses analytical approaches, where the available bandwidth is often estimated to decide whether a new SF can be admitted or not. Such methods can guarantee a non-saturated bandwidth however they cannot guarantee a satisfactory delay.

An indirect approach to the improvement of the QoS management would be the increase of the spectral efficiency of the wireless interface, as this implies the increase of the total transmission capacity of the system. This is feasible by exploiting multiuser diversity and using the AMC (Adaptive Modulation and Coding) encoding strategy that adapts to the conditions of the channel. But often this solution is not effective, because if we would to increases the bandwidth, the number of users increases and we would find ourselves in the same problem, hence the need for a CAC.

Generally, it is impossible to have an optimal solution for the spectral efficiency, QoS and fairness at the same time, because these goals are often contradictory [10]. Thus an effective compromise is necessary to secure the objectives of a strategy of resource management.

To differentiate QoS requirements, the WiMAX 802.16-2004 standard defined four classes of data stream (BE, NRPS, RTPS and UGS), the latter 802.16e version added one (ertPS). The following table describes the details associated with each class.

TABLE II. QoS CLASSES IN WIMAX

Classes	Parameters
Unsolicited Grant Service (UGS)	Maximum throughput, Maximum tolerated jitter (variation in delay) Maximum tolerated delay,…
Real-Time Polling Service (rtPS)	Maximum throughput, Minimum Throughput, Guaranteed Burst Size, Maximum tolerated delay,...
Extended Real-Time Polling Service (ertPS)	Combine UGS et rtPS.
Non-real-time Polling Service (nrtPS)	Guaranteed throughput, Maximum Throughput.
Best Effort (BE)	Maximum Throughput

D. *Mapping of Qos between Wi-Fi and WiMAX*

We can clearly notice that the mechanisms of QoS in WiMAX management are more complete and complex than Wi-Fi. This therefore leads us to stipulate that the transition of a mobile device from a Wi-Fi network to a WiMAX network is very likely to be achieved without degradation of the QoS [11, 12], given that the compliance with the conditions of the limits of saturation of the WiMAX network is respected. However, a correspondence between the QoS management criteria of the two technologies must be established (See Table III).

TABLE III. UNE CORRESPONDANCE ENTRE LES PRINCIPALES CLASSES DE QOS DANS LES RESEAUX WI-FI ET WIMAX

802.11e (Catégorie d'accès)	802.16e (Flux de Service)
AC_VO (3)	UGS
AC_VI (2)	rtPS
AC_BE (1)	BE
AC_BK (1)	BE

It should be noted that the thresholds of acceptable criteria for each type of stream remain unchanged, for example the maximum acceptable delay for a video application will not change because of the passage from one network to another.

It emerges that the QoS management in WiMAX networks is very well supported by existing standards, but should just incorporate a good (CAC) admission control algorithm so as not to degrade the QoS parameters of traffic already admitted into the network. Hence, if users have the ability to switch between several heterogeneous wireless networks, it is simply vital to integrate CAC algorithms in each network's management system to monitor the guarantee of the already allocated resources and decide if a user's network switching is desirable or not.

III. INTER NETWORK COOPERATION (STATE OF THE ART)

Multiple research works have already opened the door to the interoperability between Wi-Fi and WiMAX networks, considering the scenario where these two networks coexist and where each network provides its own QoS management. As we have already mentioned, future wireless networks are designed to provide ubiquitous universal coverage through different radio technologies for multi-access mobile nodes. However such an approach will face several challenges including:

- The selection of the radio interface to use.
- Transparent Handover mechanisms.
- Coordinated configuration of QoS mechanisms.

A future additional requirement would be that each mobile technology participating in such a configuration should be able to automatically adapt to changes in the environment or the access network. Thus arises the need for an intelligent architecture, represented by an adequately designed framework. Two relevant solutions to this problem representing two different trends were proposed in [13] and [14].

A. *First Trend [14]*

In this work, the standard IEEE802.21 plays an important role. This evolving standard defines a structure designed to enhance the mobile nodes Handover decisions based primarily on lower layers information collected simultaneously from the mobile nodes and the network access infrastructure. These informations are defined in an abstraction layer called MIH (Media Independent Handover) which is used to optimize the Handover between heterogeneous networks.

In addition to the MIH structure, the idea proposed in [13] adds additional functionality intended to supplement the autonomy of the infrastructure by adding elements that manage: the collecting of the necessary information, the handover decision and the execution of the latter at the appropriate time. In [13] the author applies his model to the case of the WiMAX-Wi-Fi convergence where management procedures of transparent Handover from WiMAX to Wi-Fi are proposed and evaluated by simulation. However, the Handover decision criteria are left open.

B. *Second Trend [14]*

The second trend in the State of the art [14] integrates an access point in a UMTS infrastructure thus creating a tight coupling between the two radios technologies UMTS-Wi-Fi Fig.2. In contrast to the first trend, the second focuses on the proposal of an optimal strategy for Handover decision without too much added modules and innovation in composite infrastructure (missing the MIH Protocol). The coupling between the two technologies is established at the level of the UMTS stream admission control. Thus a mobile station that integrates the two interfaces is directed to a Wi-Fi access preferably. If the access point becomes saturated, the access controller begins to direct connections (Handover decision) to the UMTS technology.

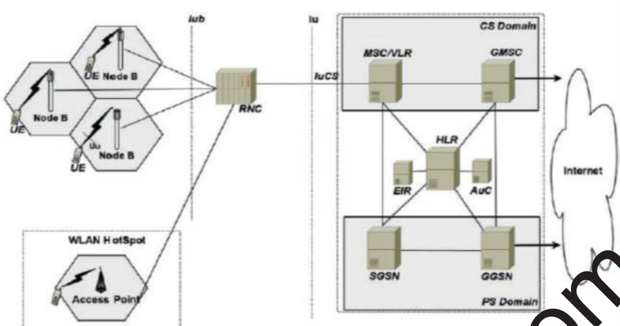

Figure 2. Tight coupling Wi-Fi-UMTS

Although our goal is similar to the work presented in [13], i.e. Wi-Fi-WiMAX convergence, we will not be using the proposed solution that we believe to be too complicated, so we opted to follow the major direction of the second solution that is simpler and easily implementable on already existing infrastructures. Evaluation of the handover strategy for the specific purpose of extending QoS from Wi-Fi to WiMAX, is in our opinion much more simple to deploy from a technical and cost perspective. Thus, we opt for a framework in which the two technologies converge in a complementary manner to improve the resulting composite global network's QoS.

IV. OUR PROPOSAL

To present our proposed QoS management strategy we will consider a network infrastructure composed of 3 groups of wired Ethernet nodes generating three stream types (video, voice and data). These groups will converse with other mobile clients using either Wi-Fi or WiMAX connections through a unique gateway, Fig.3

A. *The QoS Management Coupling strategy*

Our goal is to manage the QoS in a composite Wi-Fi-WiMAX network where the Wi-Fi QoS management would integrate the switch from Wi-Fi to WiMAX as an alternative to avoid the saturation of the Wi-Fi network or simply because the client mobile station moves away from the Wi-Fi AP, loses, or risk losing its QoS. Despite the simplistic appearance of this approach, the resulting performance depends heavily on the choice of the switch criterion.

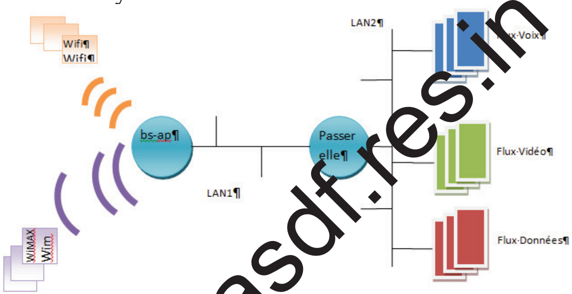

Figure 3. Proposed composite network infrastructure

In our proposal, the establishment of the switching criteria will be done in 3 steps as follows:

- We start by studying the QoS in the Wi-Fi network only. The goal is to explore the performance of QoS management of the access point based on the number of video, voice and data streams created and the distance between the station and the access point.
- In the second place, we will repeat the previous step for the WiMAX network only.
- We then link the QoS management of the Wi-Fi network with that of the WiMAX as follows:
  - Depending on the outcome of the first two steps, we will determine a limit distance that separates two zones, an area close to the gateway called Z1 and an area away from the gateway called Z2. Stations in zone Z1 are allowed access preferably in the Wi-Fi network. If the Wi-Fi network is saturated, the station is redirected to the WiMAX network. If the latter is also saturated, the station is blocked in both networks, until a decongestion of one or the other.
  - Stations in the Z2 zone are allowed access preferably in the WiMAX network. If the latter is saturated, stations are redirected to the Wi-Fi network if the latter is still attainable and not saturated.

The use of this limit distance is based on experimental results [q] that have demonstrated that the Wi-Fi network infrastructure mode allows excellent flow and optimal transmission time when client stations are close to the AP. On the other hand, WiMAX is more robust in long distances through the combination of the OFDMA (Orthogonal Frequency-Division Multiple Access) and MIMO (Multiple Input Multiple Output) methods.

V. Simulation

A. Implementations Details

The simulation is focused around two NS-3 scripts. In the first script, the management of the QoS of the Wi-Fi and WiMAX network is separate. The second script is used to evaluate the performance of the coupled QoS management strategy. In both scripts, we vary the number of nodes and the number of voice, video and data streams proportionally, and we extract the resulting network performance indicators (delay and packet lose). Initially the nodes are distributed evenly inside two discs (one for the Wi-Fi stations and one for the WiMAX stations) centered on the gateway node. The radius of each disc is incremented in each simulation step.

VI. RESULTS AND DISCUSSION

A. Results of the first script

The first script has been set to simulate 10 seconds of network activity for a number of applications ranging from 1 to 13 with a step of 2. The Wi-Fi and WiMAX nodes were distributed with radius ranging between 1 m and 581 m with a step of 20m. The PC used for the simulation had an Intel Dual Core processor with 3GigaBytes of Ram. The results for the average delay and number of lost packets are shown in Fig. 4

We note that while the number of Wi-Fi stations is less than 3, the average delay for the video and voice applications is acceptable, even when the stations are relatively distant from the AP. But as soon as the number of stations increases, the delay increases significantly. The average packet loss confirms the previous trend and reveals a notable degradation of the QoS measures around the distance of 400m for the Wi-Fi network.

For the WiMAX network, we note that the QoS performance measures are sustained over a long distance in contrast with the Wi-Fi network. Previous results were used to determine the limit distance that separates the two Zones Z1 and Z2. Thus an acceptable limit has been set for the average/maximum delay and the average/maximum number of lost packets. Subsequently, we determined the maximum number of application satisfying the acceptable limit conditions for different distribution radiuses Fig.6. We note that the number of acceptable Wi-Fi nodes is greater than that of the WiMAX for the radiuses less than 400 m, on the other hand beyond this distance the number of acceptable Wi-Fi nodes decreases while that of WiMAX remains more or less stable. Therefore we decided to take 400 m as the value for the limit distance D separating Z1 and Z2.

B. Results of the second script

In the second script we studied the performance of our coupling strategy for the a distribution radiuses varying from 301 m 601 m with a 20m step and a number of mixed nodes Wi-Fi/WiMAX ranging from 5 to 8. The results are shown in Fig.5. As soon as the two networks begin to work in perfect complementarity, QoS parameters are sustained on radiuses up to 700 m. We notice that video and voice streams QoS measures have improved significantly. After the application of the limit QoS conditions to the results of the second script, we calculated the number of acceptable mixed nodes for different radiuses Fig 6. We can notice the enhancement in comparison to the case where the two networks QoS management systems worked separately.

VII. Conclusion

In this work, we concentrated our interest in the cooperation between Wi-Fi and WiMAX wireless networks. We have built the main idea in which a WiMAX network is added to a pre-existing Wi-Fi network in order to increase the coverage area. Thus, our contribution boils down to the proposal of a QoS management coupling strategy. The latter was presented in the form of a centralized mechanism of access control of the flow of the two networks. Our proposal gives pretty good results that could still be further improved in possible future work. The prospects for this work are many and varied. Hence, improvements can be added to the coupling strategy to satisfy some alternative goals such as:

- The optimization of energy consumption.
- QoS optimization for a special class of application.
- Cost optimization.

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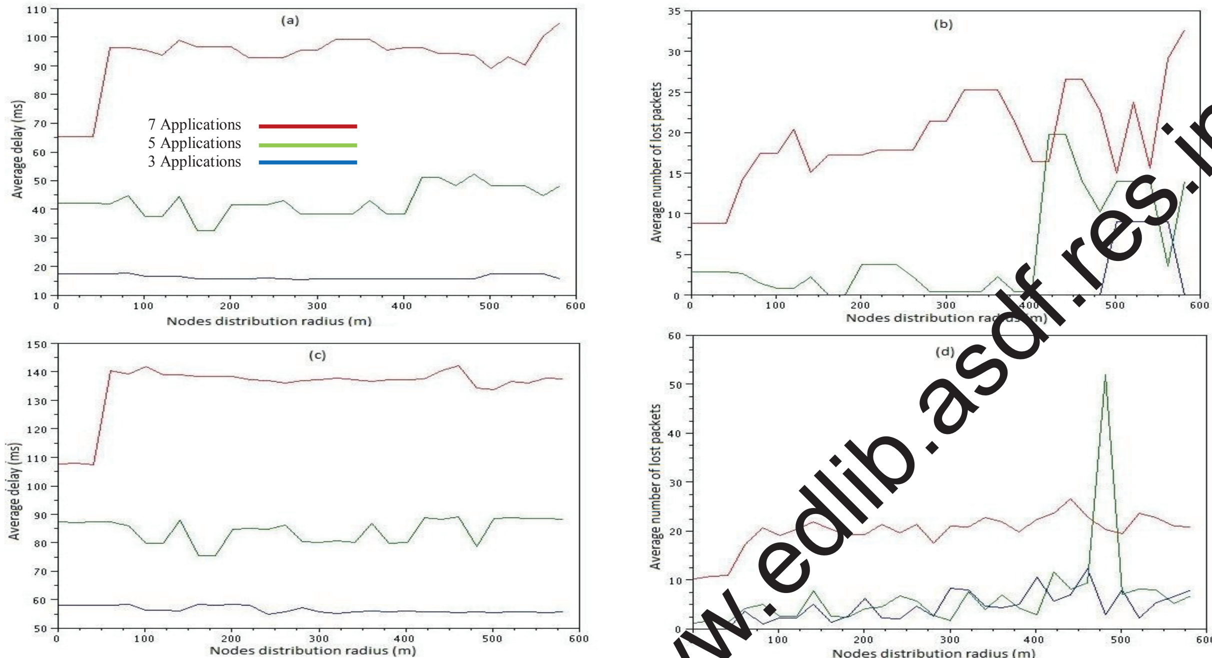

Figure 4. Video streams variation of QoS performance measures as as a function of client nodes distribution radiusfor differnet number of nodes in Wi-Fi (a and b) and in WiMAX (c and d).

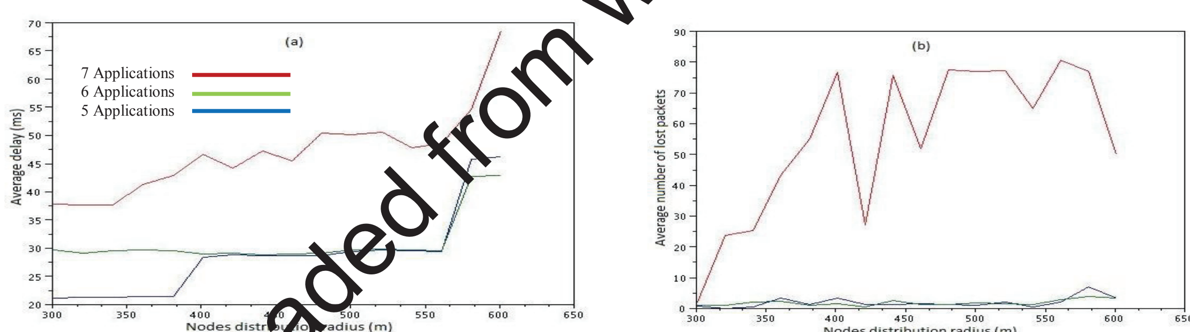

Figure 5. Video streams variation of QoS performance measures as as a function of client nodes distribution radiusfor differnet number of nodes in the mixte Wi-Fi-WiMAX network.

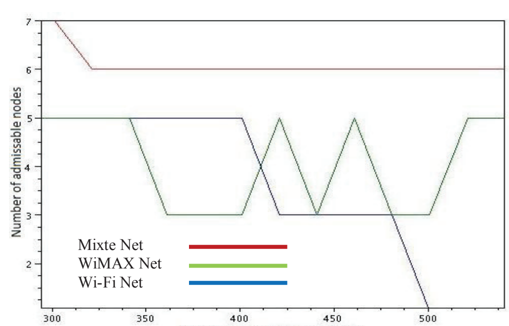

Figure 6. Variation of the number of admissable nodes as as a function of client nodes distribution radius in the Wi-Fi, WiMAX and mixte Wi-Fi-WiMAX networks.