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Highlights

- Distinct scheduling algorithms have been studied in this work
- We focus on a common scheduling algorithm for the heterogeneous wireless networks
- we propose a new dynamic scheduling algorithm
- The scheduling scheme is based on transmission links' condition from the MIH module
- The scheduling scheme is based on type of call and the classes of service.

A NEW MULTI-RAT SCHEDULINGALGORITHM FOR HETEROGENEOUS WIRELESS NETWORKS

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***Abstract*—The concept of Heterogeneous Wireless Networks (HWNs) is based on the coexistence and interoperability of different types of Radio Access Technologies (RATs) such as Long Term Evolution (LTE) and Wireless Local Area Network (WLAN) in a unified wireless heterogeneous platform. Guaranteeing the Quality of service (QoS) is an important issue for the next generation wireless networks which are characterised by providing different types of services. To schedule different types of service in HWN, distinct scheduling algorithms have been studied intensively in the literature. Thus in our research work, we focus on a common scheduling algorithm for the HWN where the traffic streams are classified into different categories, and each category has its own set of QoS parameters such as data rate and delay. In this article, we propose a new dynamic scheduling algorithm for HWN. The proposed solution introduces a new approach in scheduling packets while maintaining performance in wireless networks. The scheduling scheme is mainly based on transmission links' condition from the Media Independent Handover (MIH) module, type of call (Handoff Call Prioritization) and classes of service. In order to study the performance of the proposed scheme, we use simulation analysis and compare the performance of our scheme with a competing reference scheme called NSA (New Scheduling Algorithm) for Wireless Mesh Networks in order to reveal its ability to adapt to the specific service and channel conditions. Simulation results show that under large number of users, the proposed algorithm has lower packet loss and blocking calls ratio while offers allowable average packet delay.**

Keywords: Heterogeneous wireless networks, LTE, WLAN, MIH, scheduling algorithm, link conditions, Handoff calls, QoS.

I. INTRODUCTION

Next Generation Wireless Networks (NGWN) is expected to be heterogeneous networks which integrate different RATs such as 3GPP’s LTE and WLAN. Therefore, the coexistence of distinct RATs in the same area has necessitated Common Radio Resource Management (CRRM) to enhance

QoS provisioning as well as to provide efficient radio resource utilization.CRRM is defined, in [2], as a platform to gather information from the Base Stations (BS) or Access Point (AP) of different RATs, and to control the resource allocation of all BSs to optimize the overall system performance. HWN present different characteristics in terms of radio resources and mobility management and QoS provisioning. The issues of seamless mobility and end-to-end QoS guarantee for the users should be carefully addressed while developing interworking schemes [1]. The interworking between different wireless access networks has been a hot research topic in recent years. Most of the researchers mainly focus on interworking between WLAN and 3G cellular. Following the 3GPP approach, CRRM strategies are considered to jointly manage the radio resources belonging to multiple RATs in an efficient way. In this work we adopt the CRRM architecture introduced by the 3GPP and used in [1-3].

New wireless devices contain multiple RATs. This sort of equipment carries multiple interfaces belonging to different RATs such as laptops which are equipped with Wi-Fi, Bluetooth, WiMAX and smartphones that are provided with Wi-Fi and 2.5G/3G (BlackBerry, iPhone, and Google Android). Each RAT was designed independently. Since these different technologies have to act as complementary to each other, integration of these networks will enable the mobile users to be connected to the best available access technology depending on their requirements. This interoperability of HWN will, however, lead to heterogeneities in access. A common infrastructure to interconnect the HWN will be needed in order to meet the requirements of mobile users. The management of QoS in the infrastructure of the HWN implies the presence of specific scheduling mechanisms. In fact, in packet networks, link scheduling is an important mechanism to realize QoS as it directly controls packet delay (guarantee a particular metric value for instance, delay under 150 ms for real time traffic). Although the scheduling has a vital role in attributing priorities in a queue, most of the scheduling algorithms presented in literature propose methods which do not consider all the metrics that have an effect in the priority decision such as the dynamic aspect of the channel conditions, interference, type of calls and classes of service.

The provision of QoS to real-time communication streams is a key requirement in emerging broadband packet-switched networks. The management of QoS from the beginning to the end implies the presence of specific scheduling mechanisms. However, in some works such as [5] and [8], authors ignore the influence of the transmission link conditions, which can affect the performance when the difference of link qualities between RANs becomes evident.The well deployed cellular networks and WLANs will both be included along with other wireless access networks such as WMNs which consist of dedicated nodes called mesh routers that relay the traffic generated by mesh clients over multi-hop paths. In this article, we consider an interworking of WMNs with WLAN and LTE.

In this article, the proposed scheduling is influenced by the link condition, type of calls and classes of service that can exploit information from the MIH functions module and provide guarantee on delays. We then study a competing algorithm and evaluate its performance using simulation and compare it to our proposed scheme.

The remainder of this article is organized as follows. Related works of this research and different types of scheduling schemes are summarized in Section II. Section III describes the details of our proposed scheduling scheme and the considered network architecture. In order to highlight the contribution developed in the previous sections, various simulation experiments are run and their results are presented in Section IV. Finally, Section V summarizes the main findings of this work.

II. RELATED WORKS

The integration of heterogeneous wireless networks is bringing about revolutionary changes in the Internet by providing better Quality of Experience (QoE) assurance for users of wireless services. This recent concept called QoE is introduced in [19] and [22]. The QoE is an essential indicator for network evaluation, especially with multimedia applications. It represents perception experienced by the user. In [22], the authors propose a modular architecture called QoEH and to maximize the QoE of wireless clients in IEEE 802.11 and 802.16 systems.

In the literature, several recent researches focus on Heterogeneous Wireless Networks. In [19], the authors present a deep review of different studies of QoS/QoE in HWNs. The authors classify these works according to function within an HWN. This categorization included handover, RAT and AP selection, MAC control, scheduling, topology, power control and routing. They identify many open problems related to mobility of users in HWNs.

WLAN has been a topic of research for several years. The case study of WLAN is presented in [20] where the authors propose a novel NS3 simulation module which provides support for multi-channel Wi-Fi AP selection. The proposed solution allows user devices to scan several non-interfering channels and select the best AP according to IEEE 802.11 criteria. In [21], the authors study the problem of Access Point (AP) selection in wireless networks. They compare and classify the different approaches proposed in the literature. Then, they propose a utility-based AP selection method for IEEE 802.11 Wireless Networks. The proposed method is a passive approach that it requires no modification to the AP.

A comparative study of scheduling algorithms for real-time task was proposed in [4]. The authors classify the scheduling algorithm in two types: Fixed priority scheduling and dynamic priority scheduling. The Rate Monotonic (RM) and Deadline Monotonic (DM) are fixed priority scheduling schemes. The RM Tasks with smaller periods get higher priorities. The DM tasks are assigned priorities according to their deadline. The task with the shortest deadline is assigned the highest priority. The Dynamic Priority Scheduling contains:

-The Earliest Deadline First algorithm (EDF): This maintains a list of waiting packets to be executed. This list is sorted by deadline with the first packet having the earliest deadline. The priority of each packet is decided based on the value of its deadline. The task with nearest deadline is given highest priority and it is selected for execution.

- The Least Laxity First (LLF): It is a dynamic scheduling method. For every task ready to run at the given moment the difference S between the time until deadline D and the remaining computation time C is computed. This difference, called slack or laxity, can be seen as an inverted priority value. The task with the smallest S-value is the one to be executed next. Whenever a task other than the currently running one has the smallest slack a context switch will occur.

In [5], authors propose a novel method, based on the Point Process approximation, to analyze the expected capacity of scheduled multi-user MIMO systems. They show that the strength of this approximation is in facilitating the asymptotic analysis of the capacity of such systems in different non-uniform scenarios, where users are either inherently non-uniform or are forced to act this way due to QoS constrains. Given the number of users, they set a high capacity threshold such that only a small fraction of the users will exceed it. In each slot, the users estimate their own capacity. If the capacity seen by a user is greater than the capacity threshold, he transmits in that slot. Otherwise, the user keeps silent in that slot. They derive the expected capacity when applying QoS to the users. The expected capacity is estimated when working with a single user in each slot in the above non-uniform environment.

In [6], authors propose a Dynamic Resource Allocation (DRA) that takes into account both QoS requirements and channel status for each user. The DRA is a combinational problem where radio resources of each RAT have to be allocated to different users at each frame subject to certain restrictions in terms of QoS and the total amount of available resources. The proposed algorithm is applied in a wireless heterogeneous network to schedule the downlink transmissions of a delay-constrained service. The authors, when calculating the optimum solution of the scheduling algorithm, do not consider the delay in the intermediate nodes and the number of nodes in the path from the source to the destination which are necessary to estimate the end-to-end delay and the remaining delay before the expiration of the packets deadlines.

The authors, in [7], proposed a scheduling algorithm for HWN that guarantee QoS for the real-time traffic types. They began by developing a utility function to represent the degree of satisfaction of performing a packet scheduling in terms of avoiding wasting resource provided. The utility function is developed based on joint consideration of fairness. To find the optimal solution of the scheduling model, the authors used Hopfield neural network. A Generic Link Layer (GLL) is introduced. It is located between layer 2 and layer 3. The proposed GLL is composed of QoS classifiers, FIFO queues and packet classifier. The proposed algorithm schedules the packet to a RAT which provides higher bit rate as much as possible. The authors do not consider Handoff calls when classifying users' packets to be scheduled. The quality of channel is not considered in this scheduler. In [8], the authors propose a scheduling algorithm called SABLC based on the link condition, aiming to supporting the QoS and improving the whole network throughput in HWN.They estimate the expected delay of packet through all the available paths taking into consideration the packet loss ratio and the bandwidth. Then they schedule the packet in the link that provides the minimum predicted delay. The authors, in this work, do not consider the call type (handoff or new call) and the service class (real or non-real-time traffic). In [9], the authors propose a new algorithm for Wireless Mesh Networks (WMNs) that assigns priority to Voice over Internet Protocol (VoIP) traffic by taking into account four parameters: connection type, class of service, delay and channel quality. In this work, the quality of a link is determined by the SINR and the priority assigned to each packet is based on the earliest deadline.

III. THE PROPOSED SCHEDULINGALGORITHM

1. Architecture overview

Most of the works in this area focus mainly on interworking between WLAN and cellular networks. In our architecture, we propose to include the well deployed cellular networks and WLANs with other wireless access networks such as WMNs which consist of dedicated nodes called mesh routers that relay the traffic generated by mesh clients over multi-hop paths. In this article, we consider an interworking of WMNs with WLAN and LTE. Fig.1 illustrates an example of deployment of cellular network and WLAN. Each network is supposed to have a circular coverage area shape. Mobile users are distributed throughout the whole coverage area and can move in all directions. In the overlapped areas, users have many connection options. The user selects one RAT among all available ones in the overlapped areas.

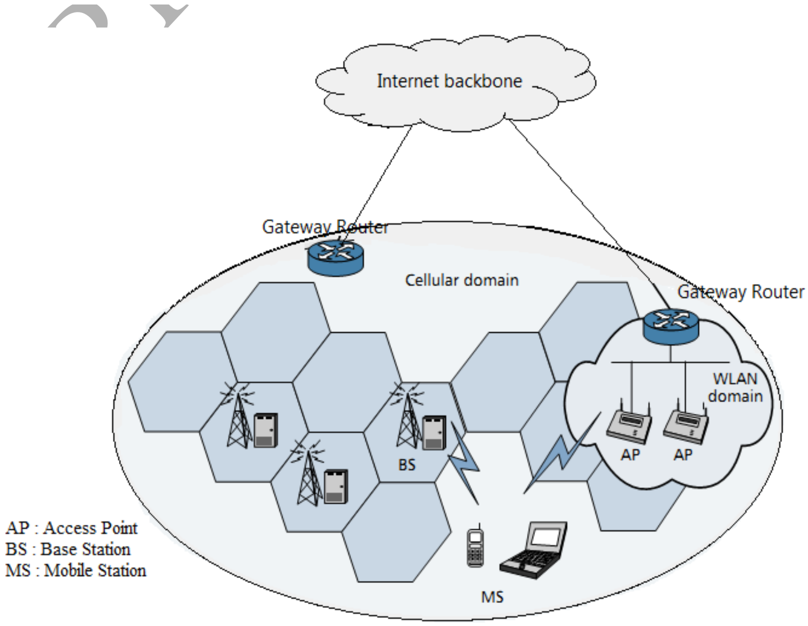

Fig.1.Interworking architecture

2. Scheduler design

A scheduling algorithm is a set of rules that determine the task to be executed at a particular moment. Packet delay control is a main goal of wireless 4G network. Each packet is assigned an end-to-end delay. According to the remaining delay for a packet before its deadline expires, we assign a priority index to that packet. Packets whose deadline cannot be met are ignored by the scheduler. The scheduler assigns the higher priority to the packet with the lower remaining delay. Some important parameters must be considered in the scheduling decision such as signal strength, interference and channel quality. Our proposed scheme is composed of four modules. Fig.2 illustrates an overview of the different modules of our scheduling scheme.

Based on [9], we propose the different modules of our proposed scheduling scheme:

- ***Classifier:*** This module is responsible for sorting the incoming packets into different service classes and forwarding them to the corresponding queues. The packets from the upper layer are classified into service flows by a packet classifier. Each packet is then pushed into the corresponding queue. MAC memory buffers are logically organized into different traffic category waiting lines. In our case, we consider two categories: real and non-real time traffics. DiffServ allows the definition of multiple traffic classes. A packet is classified according to the Differentiated Services Code Point (DSCP) field. Application with real-time constraints such as voice does not tolerate variation of the delay (jitter) between the sent and the received packets. The guarantee of these constraints becomes more difficult in technologies which take into account the mobility of the users. We need to differentiate the class of service for each packet. Real-time applications are very sensitive to the delay. Those applications such as VoIP require a limited delay and cannot tolerate a delay higher than this limit. The fixed deadlines must be met. Other types of applications tolerate an additional delay like video traffic. The non-real-time applications are not exigent in term of delay.

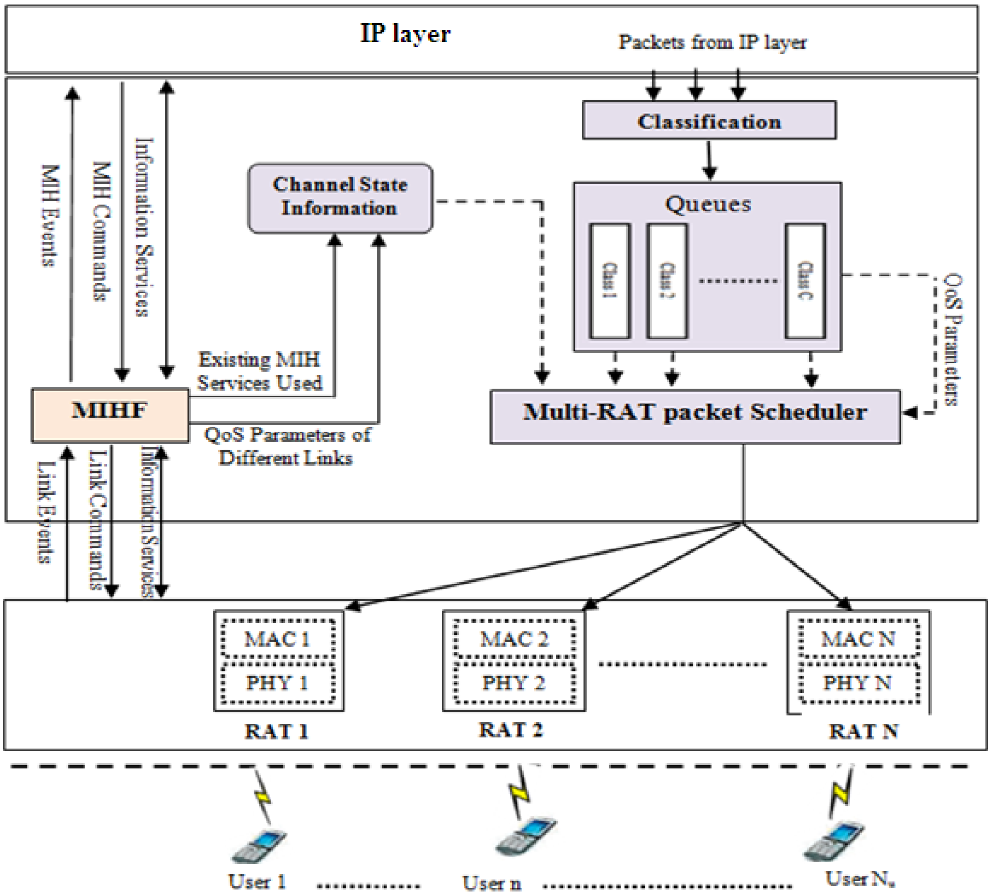

Fig.2. Functional diagram of the proposed scheduler

- ***MIHF:*** This module is responsible for providing information corresponding to the dynamic changes in the links characteristics, link quality and link status. The MIHF module sends a message to the channel state information module. The latter contains the events which are generated due to a change in the link layer parameters. These events inform about a definite change in the MAC or PHY state. These events are used to detect when a link has become available or when the radio conditions of this link are appropriate to perform a handover to this new link. Examples of this type of events are the Link Up or Link Down events.

In the IEEE 802.21 standard, the Media Independent Handover Function (MIHF) defines three main services [10] that facilitate the Handoff between heterogeneous networks: MIH Event Services (MIES), which provide link state event reporting in real-time, MIH Command Services (MICS), which allow a user to control handover link state and MIH Information Services (MIIS), which provide intersystem information, automatically and on demand [11].

The MIHF uses the following IEEE 802.21 events and commands to determine the link status and quality:

- *Link_Get_Parameters* (command): It gets parameters measured by the active link, such as Signal-to-Noise Ratio (SNR), Bit Error Rate (BER), and Received Signal Strength Indication (RSSI).
- *Link_Up* (Event): Layer 2 connection is established and link is available for use.
- *Link_Down* (Event): Layer 2 connection is broken and link is not available for use.
- *Link_Going_Down* (Event): Radio link conditions are degrading and connection loss is very likely.

- ***Channel State Information:*** The MIHF provides different information to the channel state information module. This module uses some existing MIH services such as *Link_Up*, *Link_Down*, *Link_Going_Down* and *Link_Get_Parameters* in order to determine the link status and QoS parameters of different links like data rate, throughput and other metrics. The MIES defines the functions of event classification, event filtering, and event reporting to upper layers. Specifically, different events such as ‘‘*Link_Up*”, ‘‘*Link_Down*”, ‘‘*MIH_Link_Up*”, and ‘‘*MIH_Link_Down*” are defined. ‘‘*Link_Up*” and ‘‘*Link_Down*” events are generated by lower layers (layer 1 or layer 2), and these events are notified to the MIHF. Then, the MIHF reports these situations to upper layers by triggering ‘‘*MIH_Link_Up*” and ‘‘*MIH_Link_Down*” events. Access network specific information like network identifier is provided by the MIIS IE. The channel state information module (CSIM) can be described as five-tuple:

$$CSIM = (id_{network}, id_{link}, state, SINR, CQL) \tag{1}$$

Where$id_{network}$ is the network (RAT) identifier,id_{link} is the link identifier, $state$ is the state of the link (up, down or going down), $SINR$ is the estimated SINR and CQL is the Channel Quality Levels. The major concern of the quality should be interference. If the estimated $SINR$ is larger than a threshold denoted as γ, the channel is considered good. The different levels of channel status are given by CQLwhich is defined as follows:

- Level 1: For low interference, the channel is classified as “good” channel

$$SINR \geq \gamma \tag{2}$$

- Level 2: The channel is classified as “medium” channel if:

$$\gamma > SINR \geq SINR_{req} \tag{3}$$

- Level 3: For high interference, the channel is classified as “bad” channel.

$$SINR < SINR_{req} \tag{4}$$

The channel state information module sends $CSIM$message to the scheduler module which will use this information without any channel scanning procedure. Each flow is associated with a channel, which can be in one of the three states, namely, good, medium or bad state, at any time instant.

- ***Scheduler module:*** It makes a scheduling decision according to the delay constraint, the class of service, the channel status and the type of connection (Handoff or new call). The scheduler will be discussed in details in the next section.

3. System model

In this article, we have extended the algorithm presented in [9] to include the channel quality in the calculation of the priority index. We consider heterogeneous networks composed of multiple RATs. Let R be theset of RATs. We assume that each RAT(i) $(1 \leq i \leq N)$ has a number of users of class c called $N_c(i)$ where c is the class of service in the RAT(i), and has a required SINR of class c denoted as $\mathrm{SINR}_{\mathrm{i,c,req}}$. We also consider $SINR_{i,c}(j)$ as the SINR of user *j* of class c in RAT(*i*). The total number of users in the considered area is denoted as N_u.

Let:

- $R = \{1,2, \dots, i, \dots, N\}$be the set of RATs,
- $Sc = \{1,2, \dots c, \dots, C\}$be the service class,
- $SINR_{i,c,req}$ be the required SINR of class *c* in RAT(*i*),
- $SINR_{i,c}(j)$ be the SINR of user *j* of class *c* in RAT(*i*)
- $N_c(i)$ be the maximum number of users in RAT(*i*) of class *c*,
- $D_{max,n}$ be the end-to-end delay of packet *n*,
- $D_{i,j}$be the offered delay to user *j* by RAT(*i*),
- $A_{i,k}^n$be the time when the n^{th} packet arrives at the node k in the RAT(*i*),
- $t_{j,n}$ be the time when the n^{th} packet of connection *j* arrives at its first router

A. SINR calculation

In WMN, if node *i* is transmitting to node *j*, and *E* is the set of other nodes that transmit concurrently with *i*, then the SINR of link (*i*, *j*) is given by [9]:

$$SINR_{(i,j)} = \frac{P_{ij} {d_{(i,j)}}^{-\propto}}{\sum_{k \epsilon E} P_{kj} {d_{(k,j)}}^{-\propto} + N_0} \tag{5}$$

Where P_{ij} is node i's transmitted power to j, d is the distance between the sender and the receiver, α is parameter of path loss attenuation and N_0 is the thermal noise. The summation expresses the interference generated by other nodes.

In LTE, the transmission power $P_{i,m}$ of each subcarrier m for user i, as defined in [17], is calculated as following: $P_{i,m} = \frac{P_i}{12\,|K_i|}$ where P_i is the overall transmission power and $|K_i|$ is the number of resource block (RB) in the set K_i which represent the consecutive RBs assigned to user i. Then the signal to interference and noise ratio in the m^{th} subcarrier corresponding to user i is written as follows:

$$SINR_{i,m} = \frac{P_{i,m} G_{i,m} G(\theta)}{I + P_N} \tag{6}$$

Here $G_{i,m}$ is the channel gain from user i to its enhanced-NodeB (eNB), $G(\theta)$ is the antenna gain, P_N is the power of Additive White Gaussian Noise (AWGN) and I is the power of interference which is given by: $I = I_{own} + I_{other}$ where I_{own} is the intra-cell interference power and I_{other} is the inter-cell interference. As defined in [17], $I_{own} = (1-\beta)P_i$ with $\beta \in [0,1]$ denoting the average channel multi-path orthogonality factor and P_i denoting the intra-cell transmit power. In the case of LTE, $\beta = 1$ and hence $I_{own} = 0$. In the Orthogonal Frequency Division Multiple Access (OFDMA) system, such interference is limited to inter-cell interference, as users within a given cell use sub-carriers which are orthogonal to each other.

The SINR received by user i from WLAN access point AP_j is given by [17]:

$$SINR_{AP_{j,i}} = \frac{P_{AP_j} G_{AP_{j,i}}}{\sum_{\substack{k \in AP \\ k \neq j}} P_{AP_k} G_{APk,i} + P_N} \tag{7}$$

Where P_{AP_j} is the transmitting power of AP_j, $G_{AP_{j,i}}$ is the channel gain from user i to its AP_j and P_N is the noise power at the receiver.

B. Priority index

We propose a new scheduling discipline, which we call Multi-RAT Scheduling Scheme (MRSS). The scheduler is equipped by three queues: The service queue S stores the critical packets identifiers which are selected to be served. B queue contains the identifiers of the packets which could not be transmitted because of the bad quality of the channel. The last queue D is reserved to the non-real-time packets, which are served if the S and B queues are empty. This scheduler chooses to schedule the packet that has the earliest time to expire and the best channel conditions, among all the packets. Each packet is characterized by a deadline $D_{max,n}$. Thus, they are sorted in the S queue and then served according to the delay allowed. In order to calculate the priority index of each packet, we have to begin by presenting the different constraints to be guaranteed such as delay constraints, channel status and the available resources:

- The end-to-end delay $D_{max,n}$ of real-time packets must be met,
- The offered delay $D_{i,j}$ of RAT (*i*) must be met by the packet in order to guarantee the deadline of packets as much as possible. This means that the packet must leave the network before the expiration of the offered delay. If the packet respects all the offered delay of the different access networks it arrives to destination before its deadline. Assume that the network i contains n_i nodes, the local deadline in each intermediate node *k* in the path is then calculated as follows:

$$d_{i,k}^{n} = \frac{D_{i,j}}{n_i} \tag{8}$$

In fact, some routers which are lightly loaded may transmit packets before the expiration of the delay $d_{i,k}^{n}$. We can benefit from the residual delay by adding it to the delay assigned to the next node. The residual delay is calculated as follows [12]:

$$\Delta_{i,k} = \begin{cases} 0 \quad for\ k = 1 \\ \frac{D_{i,j}}{n_i} - \left(A_{i,k}^{n} - A_{i,k-1}^{n}\right) \ for\ k > 1 \end{cases} \tag{9}$$

Then, the local deadline is as the following:

$$d_{i,k}^{n} = \frac{D_{i,j}}{n_i} + \Delta_{i,k} \tag{10}$$

Each packet is characterized by a deadline. Thus, packets are sorted and then served according to the delay allowed. Indeed, the algorithm calculates the logical arrival time $l_{i,n}$ when packet n arrives to the first router. The logical arrival time is determined based on the method explained in [9].

The proposed scheduler assigns a dynamic priority to packets according to the remaining time before its deadline expires. We begin by calculating the waiting time in a router. The waiting time of the n^{th} packet in the buffer of router *k* before transmission is the difference between the arrival and the departure time of the packet in the router. This delay represents the time spent in serving the set of packets that has higher priority than the n^{th} packet in router *k*:

$$W_{i,k}^{n} = \sum_{l=1}^{h_{n,k}} D_{tr,l} \tag{11}$$

Where $D_{tr,l}$ is the transmission delay of packet *l* and $h_{n,k}$ is the set of packets that have higher priority than the n^{th} packet in router *k*. The transmission delay is the time needed to transmit a packet, from the first bit to the last bit over a communication link. As illustrated in [12] the delay $D_{tr,l}$ is calculated as follows:

$$D_{tr,l} = ETX * T_{tr} \tag{12}$$

Here, T_{tr} is the transmission time, which is calculated by dividing packet size (S) by the estimated bandwidth (B_i) of each link ($T_{tr} = S/B_i$) and ETX(Expected Transmission Count) represents the expected number of transmissions a node needs to successfully transmit a packet to the next node.

The packet *n* arrives in router k of RAT(*i*) with a remaining time before its deadline expires equal to:

$$\delta_{i,k}^{n} = D_{max,n} - \left(A_{i,k}^{n} - t_{j,n}\right) \tag{13}$$

Where $A_{i,k}^{n}$ is the time when the nth packet arrives at the router k in the RAT(*i*) and$t_{j,n}$is thetime when the *n*th packet arrives at the first router of its path. The packet will wait $W_{i,k}^{n}$until the scheduler finishes sending the packets that have higher priority than it as illustrated in Figure 2.Then, the exactly earliest expiry time that the algorithm uses to make its scheduling decision is:

$$\delta_{i,k}^{n} = D_{max,n} - \left(A_{i,k}^{n} - t_{j,n}\right) - W_{i,k}^{n} \tag{14}$$

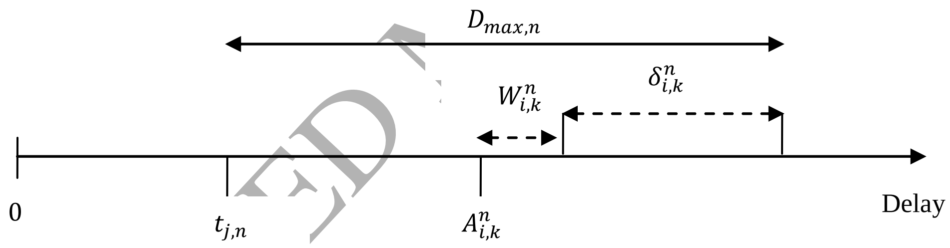

Fig.3. Computationof the earliest expiry time

We propose to assign a weight to each level of channel quality. For this reason, we compare the estimated $SINR$ with the required *SINR* and the threshold γ. If the estimated *SINR* is larger than the threshold then the channel is considered good and the weight $\theta_i^k(j)$ is equal to 1. If the estimated *SINR* has a value between the threshold and the required SINR then channel level is considered medium and the weight$\theta_i^k(j) = 0.5$. Otherwise, the channel is considered bad and the weight$\theta_i^k(j) = 0$. In order to reflect the current channel state of the user *j* in the priority index, we propose to assign a weight$\theta_i^k(j)$ to each level of channel states as follows:

$$\theta_i^k(j) = \begin{cases} 1 & if\ SINR_{i,c}(j) \geq \gamma \\ 0.5 & if \gamma > SINR_{i,c}(j) \geq SINR_{i,c,req} \\ 0 & if \quad SINR_{i,c}(j) < SINR_{i,c,req} \end{cases} \tag{15}$$

Where γ is the fixed threshold of SINR.The packet with the earliest remaining deadline and the best channel conditions is the one with the highest priority. Thus, the priority index $P_{i,k}^{n}$of n^{th} packet in router k is given by:

$$P_{i,k}^{n} = \frac{1}{\delta_{i,k}^{n}} * \theta_{i}^{k}(j) \tag{16}$$

Where $\delta_{i,k}^{n}$ is the remaining time of the n^{th} packet in router $k$before its deadline expires.

C. Scheduling algorithm

Each packet has a deadline before which it must be executed. Guarantees on meeting these timing constraints and how the system handles these packets that cannot meet their deadline, are the objectives of our proposed scheduling algorithm. The algorithm should be able to dynamically identify the packet with the earliest deadline and to take into consideration the instantaneous channel conditions. The packet with nearest deadline and the best channel quality is given highest priority and it is selected for being served. The packet will be assigned the lowest priority if its deadline is the furthest.Distinct steps can be identified based on the packet parameters and wireless channel conditions:

- On the arrival of the packet, its index priority is calculated and placed in the service queue *S*. The scheduler identifies the connection type (Handoff or new call); if it is a Handoff call the scheduler gives it the highest priority.
- The packet can be transmitted only ifthe channel condition is predicted to be good.

The proposed scheduling scheme is presented as follow:

1. **for all** packet *n* **do**
2. determine the local deadline $d_{i,k}^{n}$ in each intermediate node k of RAT(i) (Eq. 10),
3. calculate the waiting time in the k^{th} router $W_{i,k}^{n}$ (Eq. 11),
4. calculate $\delta_{i,k}^{n}$the earliest expiry time before $D_{max,n}$expires (Eq. 14),
5. calculate the priority index $P_{i,k}^{n}$of packet *n* (Eq. 16),
6. check the available bandwidth,
7. **if** the channel quality is good or medium **then**
   schedule the packet with the highest priority
   else
   store the packet identifier in the queue B
   end
8. check the end-to-end deadline, such packets are then dropped.
9. **end**

Algorithm 1: The proposed scheduling algorithm

In the queue *D*, the order of the arrival of packets determines the order in which they are forwarded to the output link. This mechanism is not used for networks, which require a classification of the flow to guarantee the quality of services for the end users.

IV. PERFORMANCE EVALUATION

In this section, the performance of the proposed scheduling scheme is evaluated via simulation, using as an example of HWN, a three RATs supporting two classes of calls; namely real-time and non-real-time traffic.

1. Simulation parameters

We simulate the heterogeneous wireless network that consists of three networks- WLAN, WMNs and LTE. The simulation topology consists of 7, 7, and 6 nodes (routers) in WLAN, WMNs and LTE, respectively. The scope of each node in WMN and WLAN is about 50 meters where the scope of LTE nodes is about 500 meters. We have considered an outdoor environment. The movement pattern selected is the Random Walk Mobility Model and the movement speed is assumed to be equal to 1 m/s.

In this work, we consider two types of traffic; Real-Time (RT) and non-real-time (NRT) traffic types. The RT applications such as VoIP require a limited delay and cannot tolerate a delay higher than this limit. The NRT applications are not exigent in term of delay such as data traffic. For maintaining a high QoS level and user perception, RT applications need to be served by networks with low delay and packet loss, while NRT applications need to be served by networks with high throughput. We assume that the mean arrival rate of new calls follows a Poisson process with parameter λ_1 for the voice service and λ_2 for the data service. Interactive users follow the www model described in [3] with an average of 5 pages per www session and 30s reading time between pages.

The simulation parameters are summarized in TABLE I. Those parameters are selected based on popularly deployed cellular networks (LTE), WMNs and WLANs in [13-18].

TABLE I. Main Simulation Parameters

	LTE	**WMN**	**WLAN**
Bandwidth	10MHz	10MHz	22MHz
Path loss exponent α	3	3	3
Data rate	100 Mbps	300 Mbps	54Mbps
Transmit power	46 dBm	20 dBm	20 dBm
Radius	500 m	50 m	50 m
$SINR_{req}$ (RT)	-4 dB	12 dB	5.5 dB
$SINR_{req}$ (NRT)	-5 dB	9 dB	4 dB
Packet size (RT)		120 bytes	
Packet size (NRT)		1500 bytes	

λ_1: Call rate (RT)	10 calls/s
λ_2: Call rate (NRT)	5 calls/s
Average call length (RT)	180s
Average call length (NRT)	600s
Movement speed	1 m/s
T_{RT} :Transmission rate(RT)	12.2 kbps
T_{NRT} :Transmission rate (NRT)	64 kbps
Simulation time	30 minutes

2. Performance evaluation metrics and results

The performance is evaluated mainly, according to the following metrics:

- The blocking ratio is a common metric of performance in wireless networks. It represents the call blocking probability, which is defined as the probability that the call cannot be accepted.
- The packet loss ratio represents the ratio of the number of lost packets and the total number of sent packets. Each packet has a deadline before which it must be executed, and if this is not possible, the scheduler tries to minimize the number of lost packets due to deadline expiry. Guarantees on meeting these timing constraints and how the system handles these packets that cannot meet their deadline, are the objectives of the scheduling algorithm.
- The average packet waiting time represents the ratio of the total waiting time of packets and the total number of packets. Each packet has an expiry time beyond which the packet is of no use to the end user. The objective of the scheduler is to send each packet before its expiry.

Fig. 4 illustrates the blocking ratio of the handoff and the new calls for RT traffic of our proposed algorithm, called MRSS, compared with a reference scheme proposed in [9].As the network traffic load increases so does the blocking probability. We note that our proposed scheme gives a light decrease in blocking rate compared with the other scheme. This difference can reach the order of 0.016 for the MRSS and 0.17 for the reference scheme in RT applications and for a number of users equals 3000. This gain can be explained by the fact that we introduce the channel conditions in the computation of the priority index in order to schedule the packets. This means that the number of blocked calls caused by the channel quality is reduced. The blocking ratio of the RT new calls reaches greater values than the RT handoff calls. One reason for this is that our algorithm assigns more priority for the RT handoff calls. The blocking probability is about 2%that is observed for simulation experiments involving more than3000 users.

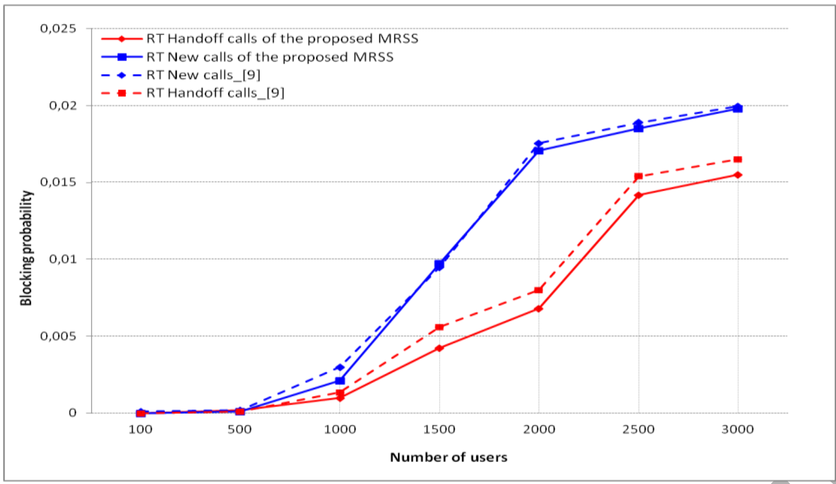

Fig.4. Real-time Handoff and new calls blocking probability vs. number of users

Fig.5 shows the non-real-time Handoff and new calls blocking probability versus the number of users in the networks. We notice that the curves begin with negligible values. Then, these rates increase gradually with the increase of the numbers of users. Indeed, for 3000 users the ratio of the blocking probability for the NRT traffic did not exceed 3%. In our proposed scheduling algorithm, the NRT packets are stored in the queue *D* and are waiting to be served when the RT queue is empty and the channel conditions are expected to be good in order to prevent packets from being lost.

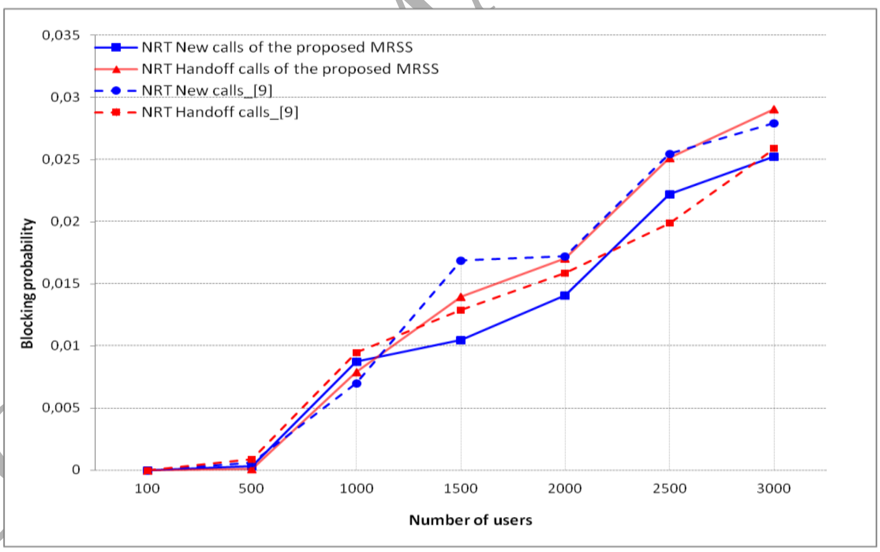

Fig.5. Non real-time handoff and new calls blocking probability vs. number of users

The fraction of packets dropped, due to deadline violation, can be used to evaluate the loss of performance of a scheduling scheme. This fraction is required to be small. Fig.6illustrates the packet loss ratio of our proposed algorithm and the algorithm proposed in [9] when varying the number of users in the networks.

The results of the proposed algorithm in [9] reach higher loss ratio than our proposed scheme. This difference can reach 0.07 for the RT traffic of our proposed solution and 0.08 for those of the reference scheme, for a number of users equals to 3000.Consequently, serving RT packets with the highest priority and with the best channel conditions minimizes the number of packets dropped due to deadline expiry.

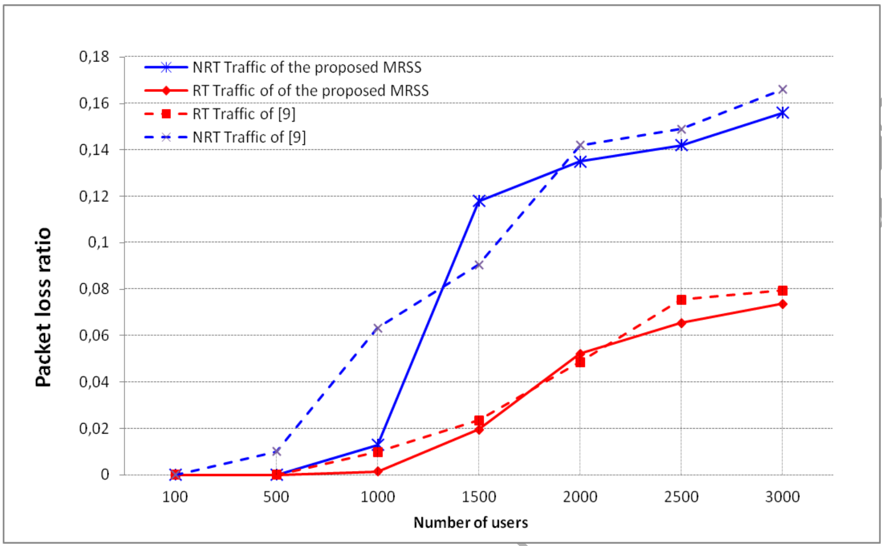

Fig.6. Packet loss ratio vs. number of users

For real-time traffic, a good measure of performance is the delay that packets incur at the router. A good scheduling algorithm should keep all delays below the deadline. Fig.7 illustrates the average waiting time versus the number of users in the different RATs. The packets of users with the second level of channel quality (medium quality) experience relatively higher delays than the users with first level (best quality), but these are still lower than the case of users with bad channel. This can be explained by the fact that we introduce the channel conditions in the calculation of the priority in order to prevent packets from being lost. Thus, the packets of users with the best channel quality have higher priority than those with the medium channel quality.

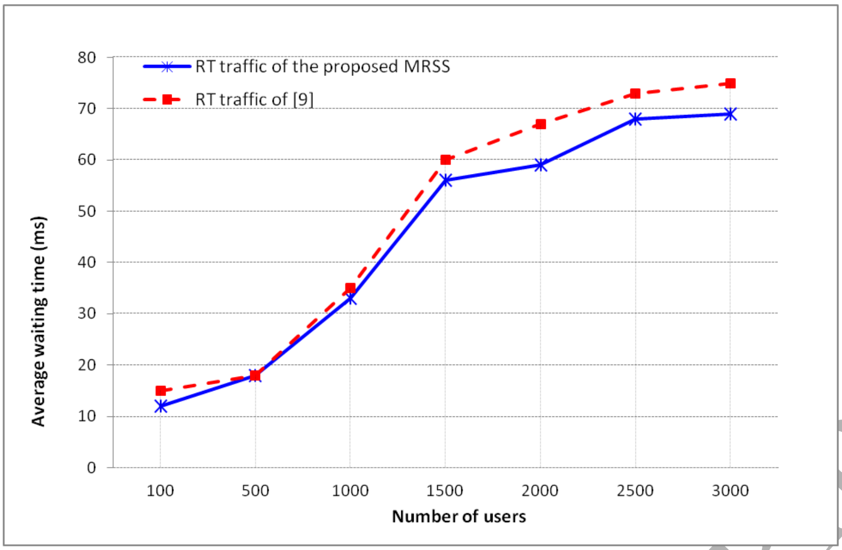

Fig.7. Average waiting time for real-time applications vs. number of users

In comparison with the reference scheme in [9], the delay slightly outperforms the delay in the proposed MRSS. This means that our scheduling can serve more packets before their deadlines expire with good channel quality. The scheduling decision depends on packet delay information, such as its waiting time and time to expire, as well as instantaneous channel states. Indeed, the average waiting time of the RT traffic in the two schemes do not exceed the delay bounds (400 ms) when varying the number of users in the networks. This delay varies between 12 ms for 100 mobile users to75ms for 3000 mobile users.

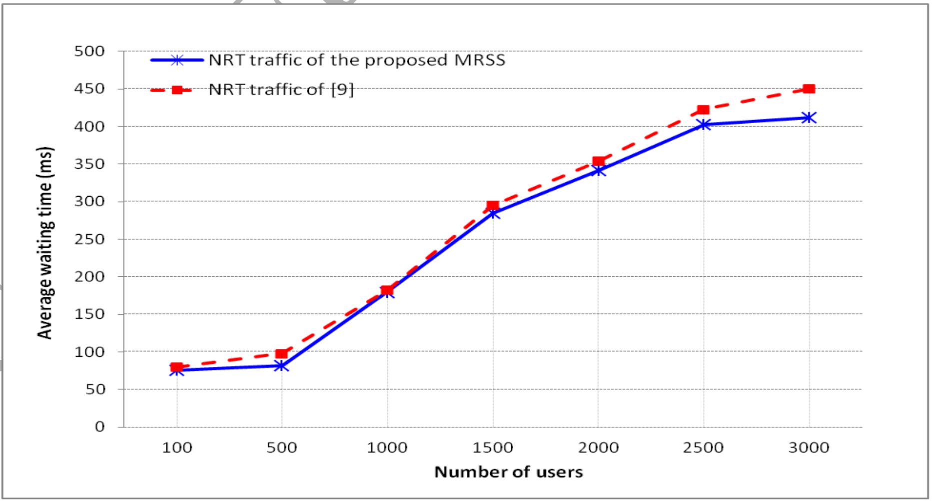

Fig.8. Average waiting time for non-real-time applications vs. number of users

Fig.8 illustrates the average waiting time versus the number of users in the different RATs for the NRT traffic.We notice that the waiting time in the curve of NRT applications exceeds 400 ms. This is explained by the fact that the NRT packets have an extra residence time, in the queues, in order to serve RT packets first. The reference scheme in [9] performs quite similar to our proposed MRS, however the reference scheme's performance begin to decrease with increased number of users. Our proposed scheme can provide guarantee on delays. It is because the scheduling decision takes into account the current channel state for each user in the system. Thus, if the channel conditions are expected to be good the algorithm schedule the RT packets in an efficient way and this may have an effect on the waiting time in the other queues.

V. CONCLUSION

The concept of wireless heterogeneous networks is based on the coexistence and interoperability of different types of RATs in a unified wireless heterogeneous platform. The management of QoS from the beginning to the end implies the presence of specific scheduling mechanisms. In this article, we address the problem of scheduling packets while satisfying QoS requirements. Thus, we proposed a new dynamic scheme based on the interworking of different RATs which utilizes some primitives from the IEEE 802.21MIH standard in order to determine the quality of the channel and then classify it into three levels by the channel state information module. The scheduling decision takes into consideration different metrics such as classes of service, connection type (handoff or new calls) and current channel state. The performance evaluation metrics used in this work are the blocking rate, packet loss ratio and average waiting time. The simulation analysis results have shown that our proposed scheme is efficient in terms of scalability and outperforms other competing existing scheme.

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