Next Generation Network Architecture for Integration of Wireless Access Networks

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***Abstract*—Motivation for the development of Next Generation Networks (NGN) concept is not only the success of mobile technology and growing popularity of IP-based multimedia services but also required cost savings, limited address space and fueling competition and collaboration. This paper proposes a solution for seamless interworking between network domains for the NGN concept. More specifically, seamless interworking is described for WLAN, WiMax and UMTS/LTE networks. The proposed architecture is an all-IP design. We introduce a heartbeat mechanism between WLAN, WiMax and UMTS/LTE using the IEEE 802.21 Media Independent Handover (MIH) Information Service, which enables low handover latency by reducing the target network detection time.**

Keywords*- *NGN; WLAN; WiMax; UMTS; LTE; QoS; IEEE 802.21 MIHF; interworking; domain coupling.

I. INTRODUCTION

Not only the huge success of mobile technology and growing popularity of IP-based multimedia services are motivating the development of Next Generation Networks (NGN), but also saving costs, open for more address space and lowering threshold for more actors. NGN is described as the convergence of public switched telephone network, the wireless networks and the data networks.

The combination of cellular networks and wireless networks meets the need for wide range and high data rate. In effect, this provides better service to users. To approach such a combination this paper proposes a next generation scheme for seamless interworking between WLAN [1], WiMax [2] and UMTS/LTE [3] networks hereby called WLAN-WiMax-UMTS/LTE Interworking Architecture. This paper is a continuation to [4] which proceeds with proposing a framework to provide service mobility following the NGN architecture and uses the IEEE 802.21 MIH services to exchange information by introducing a control plane with MIH information severs to guarantee connectivity while using best network selection (see Figure 1). This paper proposes how to integrate wireless access networks in the access plane of the proposed framework.

The paper is structured as follows. Section II summarizes the types of integration and pros and cons of those types of integration. Section III proposes the next generation WLAN-WiMax-UMTS/LTE Interworking Architecture. Section IV describes Heartbeat Messages and Section V discusses how QoS parameters are measured in the proposed scheme. Section VI gives analytical evaluation of the heartbeat mechanism. In the last section, the paper is concluded.

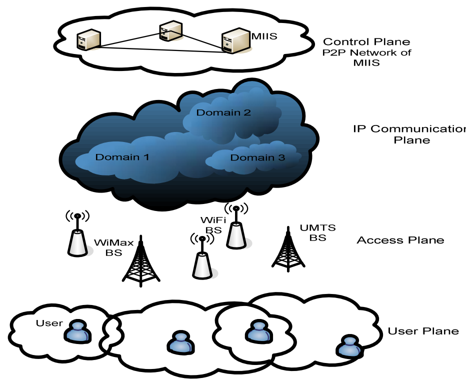

Figure 1: Proposed NGN Architecture [4]

II. TYPES OF ACCESS NETWORKS INTEGRATION

Two approaches for integration of wireless (e.g., WLAN) and cellular (e.g., UMTS) networks have been defined by ETSI – loose coupling and tight coupling. In loose coupling (Figure 2), wireless and cellular networks are not directly connected. They do not share a common protocol stack. Hence, this results in fairly long handover latency and potential packet loss.

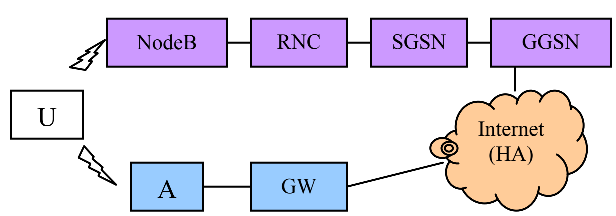

Figure 2: Loose Coupling WLAN-UMTS Interworking

One advantage is that it allows independent deployment and traffic engineering of WLAN and UMTS. Roaming agreements with partners can allow widespread service enabling subscribers to use a single service provider for all network access. Another advantage is that it allows a WISP (wireless internet service provider) to

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provide its own public WLAN hotspot, interoperate through roaming agreements with public WLAN and UMTS service providers or manage a privately installed enterprise WLAN. Loose coupling is commonly implemented by use of Mobile IP.

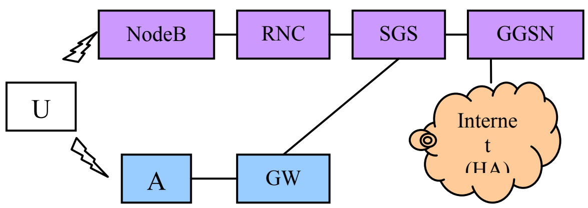

Figure 3: Tight Coupling WLAN-UMTS Interworking

In tight coupling, a wireless network is connected to cellular network just like any other radio access network (see Figure 3). Wireless network emulates the functions similar to GPRS functions [7]. Advantages of tight coupling include seamless handover across WLAN and UMTS, reuse of AAA, reuse of infrastructures, increased security, common provisioning and customer care and access to core UMTS services like SMS, MMS and location based services. One disadvantage is that tight coupling needs to be tailored for WLANs owned by cellular operators and does not easily support third party WLANs. The same operator must manage both WLAN and UMTS parts since the core network interfaces are exposed. Another disadvantage is that tight coupling does not straight forwardly support legacy WLAN terminals that do not implement the UMTS protocols. Cost and capacity of the SGSN associated with the connection of WLAN may also be a disadvantage. While throughput capacity of traditional SGSNs is sufficient to support thousands of low-bit-rate GPRS terminals, it may not be sufficient to support hundreds of high-bit-rate WLAN terminals. Thus SGSN could become a bottleneck for high data rate applications.

The integration architectures, as explained in [5], differ for each of the interworking options, as shown in Figure 4.

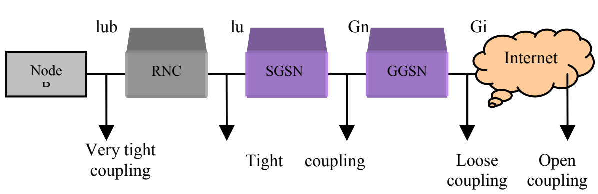

Figure 4: Interworking points with the relevant architecture names (based on [5])

WLAN can be integrated with UMTS at PS core. Depending on which point it is attached to – it is loose, tight, very tight or open architecture.

Note that in this section, WLAN and UMTS are used as examples of wireless and mobile systems. The description can be made more general including systems such as WiMax, LTE and others.

III. Next Generation Proposed Architecture

The design of an architecture that efficiently integrates WLAN, WiMax and UMTS/LTE is a rewarding task. In the following a scheme for integration of cellular and wireless networks is described. The case of WLAN, WiMax and UMTS is chosen for illustration as shown in Figure 5.

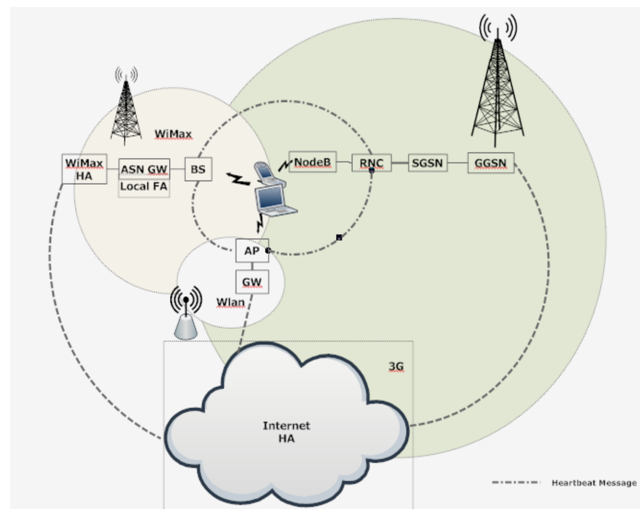

Figure 5: Proposed Integration of Access Networks

A. Architecture

We assume that neighboring WLAN Access Point (AP) and UMTS Base Station (BS)/ Radio Network Controller (RNC) and WiMax BS are connected via a backbone network. The APs and nodes are capable of verifying the identity of neighbor APs and nodes. The User Equipment (UE) has multi radio interfaces and protocol stacks for WLAN, WiMax and UMTS. Note that different classes of UEs can be present, some able to make use of multiple radios while others are not.

The significant characteristic of the proposed architecture is that the UE needs not have all the interfaces on all the time. The list of all available networks can be retrieved from any one of the interfaces – WLAN, WiMax or UMTS using the IEEE 802.21 MIH Information Service Request.

AP, BS and RNC are connected, i.e., they can identify each other and can share information with each other, either directly or via a mediator. They share information with each other by way of periodic heartbeat messages using IEEE 802.21 Media Independent Handover (MIH) Information Service Messages. A UE initiating a session can get relevant network and QoS information depending on type of service. The network selection can then be either made by UE or by network node (including AP/ BS/ RNC) to provide seamless handover and service continuity.

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B. *WLAN-UMTS interworking*

One motivation for WLAN-UMTS interworking is to extend UMTS services and functionality to WLAN access environment [11]. Additional capacity and higher data rates for end users on WLAN and operation of WLAN on unlicensed frequency band makes it all the more suitable for WLAN-UMTS interworking. Figure 6 summarizes the UMTS-WLAN interworking characteristics [12].

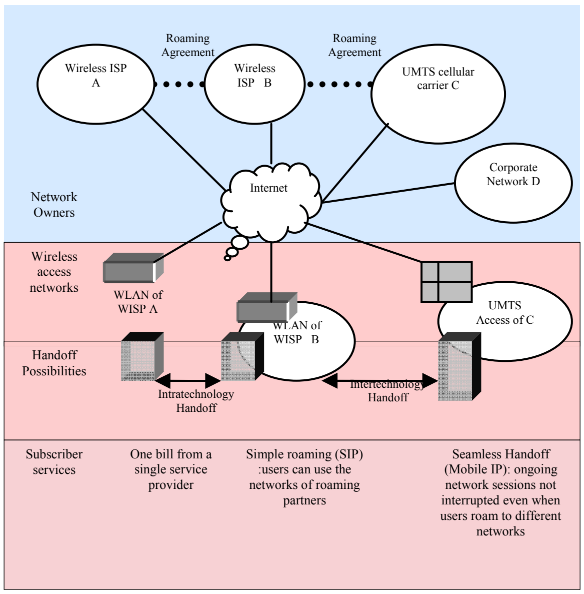

Figure 6: WLAN–UMTS Interworking (adapted from [12])

We propose a scheme where AP and RNC (Radio Network Controller) forward packets to each other intelligently. WLAN and UMTS are indirectly connected through an IP-based network which means a loosely coupling architecture. Mobile IP can be used to roam between WLAN and UMTS networks. An enhancement of the existing architecture is the introduction of communication mechanism between APs and RNCs/network nodes using IEEE 802.21 MIH with heartbeat messages as explained in Section IV. One option is to allow APs and network nodes to obtain information via multi-radio interfaces. Another option is to allow UEs reporting on the conditions observed. In the former case, AP and network nodes periodically broadcast heartbeat messages to all neighboring nodes including other radio interfaces using IEEE 802.21 MIH messages.

On receiving the heartbeat messages, AP and network nodes update the network map information. This way, all relevant nodes know the existence of other access networks including the relevant network attributes. This information is later used for making optimum network selection before handover.

C. *WLAN-WiMax interworking*

WLAN offers high data rates within a 100 m range whereas WiMax offers lower data rates in an 8 km range [6]. Instead of selecting one network to provide access to network services, interworking both networks can use each network’s advantages. Service providers can provide bundled services to users in either access network thereby using both licensed and license-exempt frequency bands. In this way, service providers can sell attractive devices supporting WiMax and WLAN capabilities taking advantage of device cost savings [8].

In the proposed architecture, WLAN and WiMax are integrated at the IP layer following the NGN concept [7]. In the proposed integration, a WiMax BS or WLAN AP periodically broadcasts heartbeat messages giving neighbor network information to relevant nodes. Any AP or BS in the vicinity will receive these messages. It is assumed that AP and BS will stay on and listen on those interfaces. In effect, AP and BS neighbors can assist when selecting the best available network. This may reduce target network detection time. The heartbeat messages follow the format of IEEE 802.21 MIH messages. The heartbeat message format is given in Chapter IV.

The difference between this proposal and those given in [8][10] is that the target network detection time is reduced. The IEEE 802.21 MIH Information Service heartbeat messages minimize the target network detection time. Since a current network admission controller (e.g., residing in AP/BS) is aware of the target network (post handoff), the handover latency is reduced.

D. *WiMax - UMTS interworking*

WiMax – UMTS may be partially overlapping as opposed to fully overlapping commonly seen for UMTS – WLAN (see Figure 7), [14]. In the latter case, the UE may maintain the Packet Data Protocol (PDP) context of UMTS while simultaneously being connected to WLAN. Hence, when the UE leaves the WLAN spot, it can reconnect immediately to UMTS without reactivating PDP context. However, since WiMax coverage may be partially overlapping UMTS, the handover needs to be fast enough to maintain service continuity.

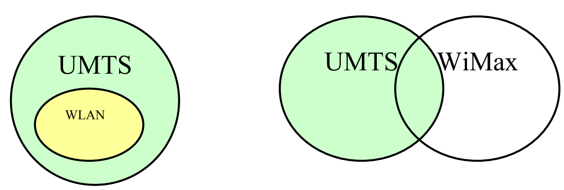

Figure 7: WLAN-UMTS Vs WiMax-UMTS

To achieve this, Mobile IP can be used as common interconnection protocol. The WiMax BS and UMTS node must then interwork. The WiMax Access Network (ASN) provides the WiMax access services for the UE. WiMax Home Agent (HA) manages the mobility inside WiMax network. The WiMax HA is not included in UMTS core network to keep its independence (loose/open coupling). The Foreign Agents (FAs) located in ASN Gateway are considered as the local FAs in the interworking architecture. A common AAA network could be utilized. GGSN manages

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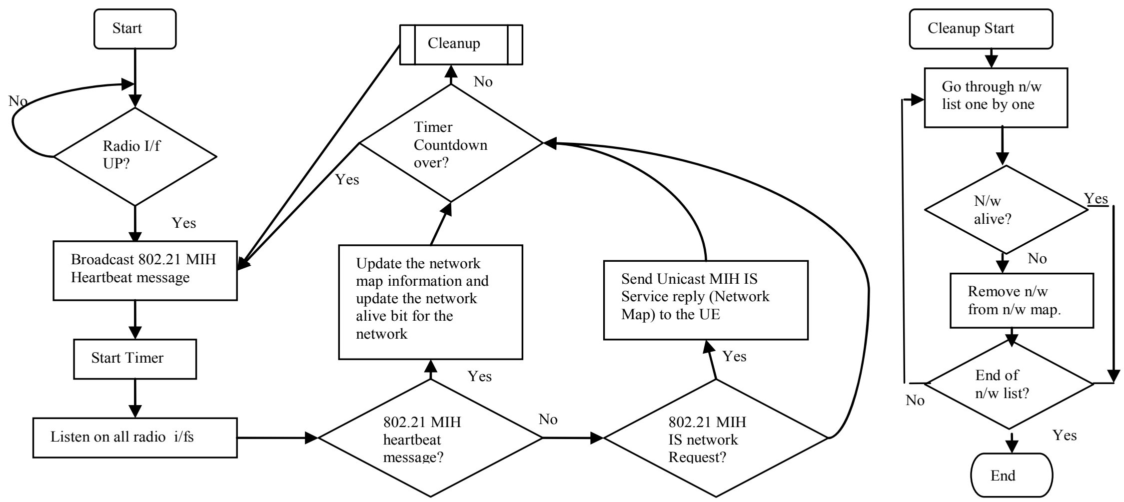

Figure 8: Flowchart for Heartbeat Mechanism at AP, BS, RNC

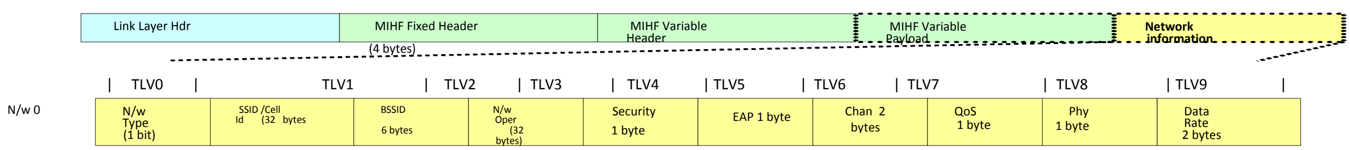

Figure 9: Heartbeat (Network Information) Message

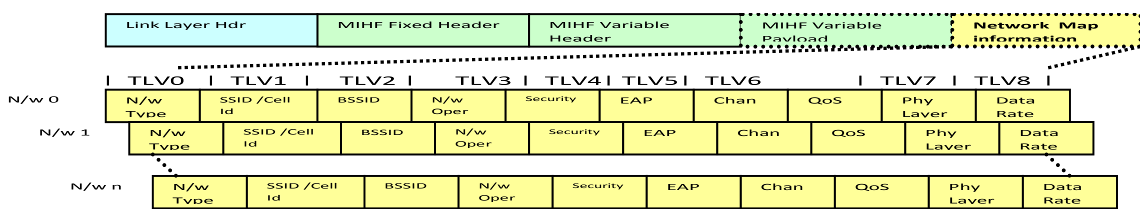

Figure 10: Heartbeat Message Information Service Reply (Network Map) Format

the mobility and FA functions in UMTS network. The major advantage of this proposal over the proposal in [14] is the seamless handover and low packet loss. It is achieved through IEEE 802.21 MIH based heartbeat messages. This method guarantees both the independence of between networks, and low handover latency.

IV. HEARTBEAT MESSAGES

IEEE 802.21 MIH messages make the heart beat message uniform across different access networks. The timing of these messages will also be independent. The message format is as shown in Figure 9. This is in TLV format as required by IEEE 802.21 Variable Payload. Network attributes are periodically distributed to every relevant node. Each of the nodes listens on for heartbeat messages from other nodes. They form a network map based on the information received through heartbeat messages. On receiving the heartbeat message, they update their network map information periodically. UE can either retrieve the network list from any of them or can issue an MIH Information Service Request for Network Map Information on all its radio interfaces. As shown in Figure 8, the node multicasts its network information using IEEE 802.21 MIH messages on relevant interfaces. Being a periodic message, the AP will send the heartbeat message every n time units. So a timer is used to count for this purpose. Meanwhile, AP also listens on relevant interfaces for heartbeats from other nodes. On receiving an IEEE 802.21 MIH packet on any interface, AP checks what type of packet it is. If it is a heartbeat message, AP will update the network map information and marks the entry alive. If it is a network request message from a UE, AP sends the network map information to the UE. If the timer expires it goes through the network list and checks whether the network is still active. If the network is not active, that entry is deleted from the network map. This way all the entries in the network map are checked. Responses are shown in Figure 9 and Figure 10 which is in TLV format as required by IEEE 802.21 Variable Payload. This communication mechanism enables faster handovers by referring to the available network map information.

V. QoS NETWORK PERFORMANCE PARAMETERS

ITU recommendation for the service classes and QoS parameters mapping for various access technologies are given in [4]. QoS parameters are collected by every network. These include parameters like delay, throughput, packet error ratio, average packet transfer delay and jitter. For example, transfer delay is measured by measuring the time required by a packet to travel from ingress to egress of a node (e.g., AP/BS). The IN timestamp and OUT timestamps are stored and their difference gives the packet delay.Average packet delay is calculated as accumulated packet delay divided by number of packets transmitted successfully.

Similarly, packet error ratio is given by the number of failed transmissions over total transmissions. Throughput is the maximum sustained traffic rate for WiMax, Maximum Bit rate and Peak rate for UMTS/LTE and Peak Data Rate for WLAN. This is kept track of by relevant network nodes. Using the standard formulas for M/M/k/m queue model, [4], delay and throughput parameters can be calculated by the individual network nodes. Similarly, call blocking probability can be calculated using analytical model proposed in [15] in terms of number of virtual channels (N), user arrival rate (λ), arrival rate of type1 call ($\lambda 1$), arrival rate of type2 call ($\lambda 2$) arrival rate of type3 call ($\lambda 3$) and service time of the user (μ)].

Handoff Call dropping probability may be calculated as given in [16] [17].

$$P_d(n,g) = \frac{\frac{A^{n-g}}{n!} A_1^g}{\sum_{i=0}^{n-g-1} \frac{A^i}{i!} + \sum_{i=n-g}^{n} \frac{A^{n-g}}{i!} A_1^{i-(n-g)}}$$

Note: if we set $g = 0$, the above expressions reduces to the classical Erlang-B loss formula [17]. Where Pd - Call dropping probability, g – number of channels reserved for handoff calls, n – Number of idle channels and A – Call arrival rate / (call completion rate + handoff departure rate). The QoS network performance measurement parameters (Delay, Throughput, Call Blocking probability and Handoff Dropping probability) are piggybacked to heartbeat messages as shown in Figure 11.

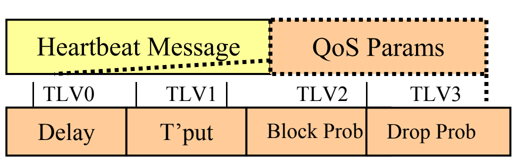

Figure 11: QoS Params

The QoS Network Performance Measurement parameters can then be used to rank the access networks and finally select the best available network. A network ranking algorithm will require the QoS parameters to make optimum decision suiting the network requirements of UE. For example, if UE is connected to WiMax and is moving another network may become available, such as UMTS and WLAN. Say, if call dropping probability of UMTS is higher than for WLAN, and the ranking algorithm should place higher desirability to WLAN and rank it better than UMTS. These parameters are the key factors that decide the desirability of a network when making a network selection decision.

VI. ANALYTICAL EVALUATION

In this section, we analyze the costs involved to find whether the proposed system is better than existing loose coupled architecture. Consider a UE is connected to one of the access networks – WLAN, WiMax or UMTS. Say there are x networks available to UE. The UE sends x requests to find available networks to perform a handover and receives x responses about available networks (if all are still available).

So, for detecting the target networks in conventional loose coupling architecture, the UE will have to exchange at least $2x$ packets to find characteristics about x access networks. This is best case scenario. The ACK packets and retransmissions due to error are not even considered here.

Handoff Latency (LH) can be expressed in terms of detection delay (LD), handoff request delay (LHR) and handoff response (LHS) delay.

$$LH = LD + LHR + LHS$$

The proposed architecture aims at minimizing the detection delay thereby reducing the handoff latency. [18] Shows, by simulation, that detection delay is a significant component of Handoff latency. The data rates differ, however, for WLAN, WiMax and UMTS. Together with the different network solutions implies that responses will arrive at the UE at different times and reflect different time intervals. Some examples of data rates are given in Table I.

TABLE I. DATA RATES FOR WLAN, WIMAX & UMTS

WLAN	***Mobile WiMax***	***UMTS***
54 Mbps	40 Mbps	2Mbps

In the proposed architecture, UE sends MIH Network Request Message and receives the network Map information through the IEEE 802.21 MIH Network Map Message. So, in all 2 packets are exchanged to get the list of available networks. Let Dwlan –Time to transfer a packet on WLAN, Dwimax – Time to transfer a packet on WiMax and Dumts– Time to transfer a packet on UMTS. In Loose coupling architectures given in [8][10], [14]; Time to detect x networks when UE is connected to (serial request - response) WLAN= 2 * x * Dwlan. Time to detect x networks when UE is connected to WiMax = 2 * x * Dwimax. Time to detect x networks when UE is connected to UMTS= 2 * x * Dumts.

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For the architecture described in this paper, time to detect x networks when UE is connected to WLAN = 2 * Dwlan, time to detect x networks when UE is connected to WiMax = 2 * Dwimax and time to detect x networks when UE is connected to UMTS= 2 * Dumts. So, to detect available networks on each of the access networks, the cost involved in terms of time units is summarized in Table II.

TABLE II. CALCULATIONS SHOWING DETECTION DELAY LD

	Number of Access networks	***Time to detect on WLAN***	***Time to detect on WiMax***	***Time to detect on UMTS***
Loose coupling Architecture	x	$2 * x * D_{wlan}$	$2*x* D_{wimax}$	$2 *x * D_{umts}$
Proposed architecture	x	$2* D_{wlan}$	$2*D_{wimax}$	$2*D_{umts}$

As shown in Table II, the detection delay LD is only a multiple of the packet transfer delay in each of the access networks. However, for other architectures, LD is a multiple of both the number of access networks (serial detection) as well as the packet transfer delay. With increase in the number of networks available, the detection delay will also increase. The numbers of messages are also increasing correspondingly. For serial detection, the delay will be equal to the one proposed in this paper only when $x = 1$. That is, only when one network is available.

VII. CONCLUSION

In this paper, we have proposed a next generation WLAN-WiMax-UMTS interworking architecture. This is based on NGN architecture (which follows 3GPP standards) and proposes a novel heartbeat mechanism using IEEE 802.21 MIH Information Service. The architecture promises a low target network detection time during the switching of the communication. The mobility between two access networks is achieved by the Mobile IP at the network layer.

The QoS Network Performance Measurement Parameters are piggybacked to heartbeat messages and shared with other access networks. We have shown how proposed architecture can minimize detection delay, and ultimately reduce the handover latency. Our future work will focus on handover algorithms and ranking algorithm for access networks based on the proposed architecture and their performance evaluation through simulation.

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