# A Novel Multi-hop B3G Architecture for Adaptive Gateway Management in Heterogeneous Wireless Networks

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*Abstract*— **In this paper, a Multi-hop B3G architecture, which is a Heterogeneous Wireless Network (HWN) architecture, integrating MANET, Infrastructure WLAN with 3G UMTS network, is considered for the purpose of providing anytime, anywhere data access as it utilizes the higher bandwidth rates of MANET and WLAN networks and wider range of communication of 3G network. The issues of Gateways in HWN, which serve as a liaison between the MANET/WLAN and UMTS, are analyzed in this paper. A multi-metric Gateway Selection mechanism using Simple Additive Weighting (SAW) of MANET node metrics such as residual energy, 3G signal strength and mobility speed, is used to select an optimal Gateway from the dual-interface-enabled Gateway Candidates. As transaction progresses, when the above-mentioned metrics of the Gateway reach their respective pre-defined threshold values, thereby, affecting optimality of the current Gateway, a Multi-metric Adaptive Gateway Migration Mechanism (MAGMM) is proposed, which migrates the responsibility of the current Gateway to a newly-selected optimal Gateway, in order to sustain connectivity of the integrated network. This MAGMM is incorporated in the considered multi-hop B3G architecture and hence it is termed as Adaptive Gateway Management-based Multi-hop B3G Network (AGMMB3G) Architecture. In addition to MAGMM, this paper also compares AGMMB3G with the other existing HWN architectures. Simulations are carried out in HWN environment using NS2 and the results show how MAGMM enhances the overall HWN performance in terms of Transaction Duration, Packet Delivery Ratio and Control Packet Overhead parameters.**

*Index Terms*— **Adaptive Gateway Management, Gateway Migration, HWN Architectures, Multi-hop B3G, Seamless Integration**

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## I. INTRODUCTION

TODAY'S research, in the wireless networking domain, heavily involves utilization of various wireless technologies for data sharing and data services. Seamless Integration of multi-hop IEEE 802.11-based Mobile Ad hoc Networks and 3G cellular networks have tremendously contributed to the evolution of Wireless communication systems of Beyond third-generation (B3G) [1], which are emerging for the purpose of any-time, any-where data access. B3G networks are a kind of Heterogeneous Wireless Network (HWN) systems [2], [3], which form the prime requirement for next generation communication services. 3G networks provide data services over cellular networks via an Internet backbone, thereby, enabling data access to cellular end-users. Universal Mobile Telecommunication System (UMTS), a 3G network, provides a peak downlink data rate of 2Mbps, up-link data rate of around 384Kbps and a wide-range of communication of around 20km per Base Station Transceiver (BST). At the same time, IEEE 802.11-based networks can run in an infrastructure-less, de-centralized ad hoc manner, enabling peer-to-peer communication. An enhanced version of these networks is IEEE 802.11b, providing an unlicensed frequency band of 2.4Ghz, an indoor coverage up to 250m and offering data rates up to 11Mbps. Mobile ad hoc networking principles enable mobility feature to nodes in ad hoc network such that they exhibit random motion across the network, resulting in an arbitrary and dynamic topology. In order to couple high data rate and wide-range of communication, the UMTS service can be extended over IEEE 802.11b networks.

A Gateway node [1], [4] is the dually-interfaced intermediate node that enables data transfer from the nodes of the MANET across the external UMTS backbone network. It is configured and enabled with dual interfaces of 3G and IEEE 802.11b. The issues involved in the heterogeneous integration of these two network interfaces within a single Gateway node are discussed and used in simulation. The significance of the Gateway and its related issues, such as Gateway mobility and migration, has not been extensively studied in the literature.

### *A Motivation of Research*

There are several issues involved in the seamless integration

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of HWN. Analysing and addressing these issues form the motivation of research. HWN involves establishment of end-to-end connectivity, requiring proper interfacing of the gateway candidate nodes with both the IEEE 802.11 and the 3G networks, as discussed in [1], since these two networks exist in two different spectrum regions. Next, an optimal Gateway Selection mechanism is required for MANETs, to be a liaison with the 3G cellular network, for data communication. There are also several gateway-centric issues such as mobility, depletion etc., which need to be handled for optimal performance of the network. The next issue lies with choosing an optimal gateway discovery mechanism. Gateway discovery mechanisms are either pro-active or reactive. Pro-active mechanism involves periodic Gateway Advertisement (GWADV) broadcast by the gateway, which minimizes delay required in finding out the Gateway. Whereas, reactive mechanism involves reactive Gateway Solicitation (GWSOL) forwarding by MANET nodes, which minimizes the control packet overhead required in discovering the gateway. This paper addresses these issues by devising a multi-hop B3G architecture and proposing an Adaptive Gateway Management mechanism.

A critical review of the above-discussed literature shows that the dynamic and infrastructure-less issues of Gateway such as mobility, depletion have not been sufficiently explored. Since gateway plays a major role in sustaining the connectivity between networks, this research focuses on enhancing the optimal behaviour of the integrated Network by addressing gateway-centric issues. Moreover, the literature has not addressed a common routing protocol for end-to-end routing in HWN. The routing protocol should be designed so as to integrate the routing mechanisms, used in individual networks, at the hybrid multi-interfaced Gateway and Access Point nodes.

## II. PROPOSED HETEROGENEOUS WIRELESS NETWORK ARCHITECTURE

The architecture of a multi-hop B3G network system, a kind of a heterogeneous wireless network architecture, considered in this scenario, is shown in figure 1. It comprises of nodes of IEEE 802.11(b) and 3G-UMTS Networks. The IEEE 802.11 standard defines two modes, namely infrastructure and ad hoc. In the former mode, each IEEE 802.11 mobile node communicates directly with the Access Point, while, in the latter mode, each IEEE 802.11 mobile node communicates with each other on a peer-to-peer basis. Both these modes have been involved in the Architecture shown in figure 1.

The MANET is multi-hop and the nodes of MANET are infrastructure-less and their mobility and seamless roaming can extend the UMTS service over a wider area than the deployment of stationary ad hoc nodes, discussed in [1]. The main components of the UMTS network, referred from the UMTS Architecture [5], are Radio Network Controller (RNC), Mobile Station, Base Station Transceiver (Node B), Serving GPRS Support Node (SGSN) and Gateway GPRS Support Node (GGSN) as shown in figure 1. The MANET gateway accesses the UMTS network via Node B (BST) over the UMTS radio interface. The Node B is in turn connected to the RNC. The UMTS network is connected to the external IP networks through GGSN. SGSN is responsible for routing data packets to the correct RNC from GGSN and vice-versa. The main objective of the paper is to, first, determine gateway candidate nodes and enable the dual interfaces on them.

Referring to the architecture in figure 1, the region within the MANET where the 3G signal strength is intense is termed as the 3G Active Region. The nodes of the MANET are configured with the UMTS and IEEE 802.11(b) interfaces, but the UMTS interface is not enabled on all MANET nodes.

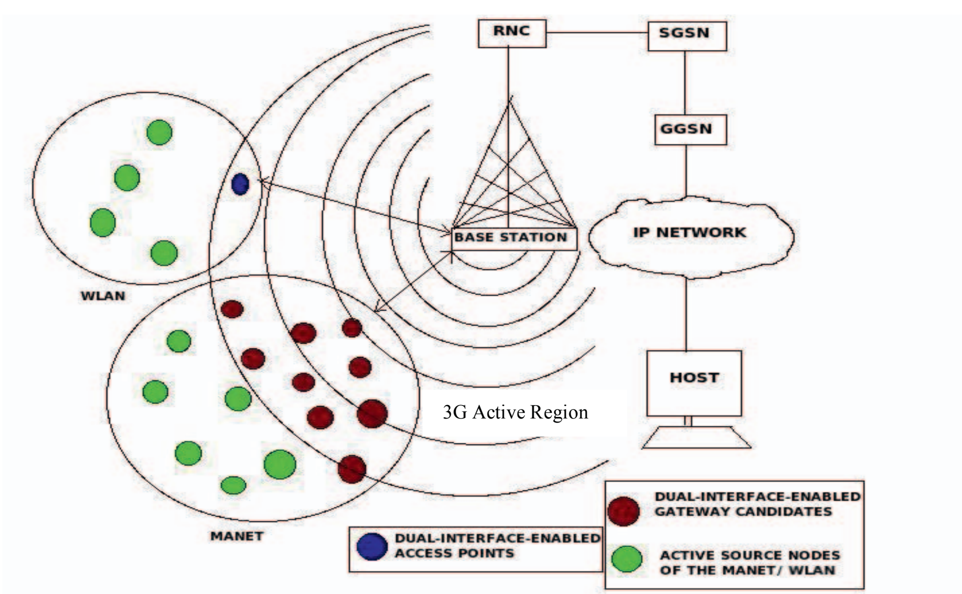


Fig 1 : Proposed Multi-hop B3G Architecture with Gateway nodes.

Only those MANET nodes lying within or moving to the 3G network are enabled with the UMTS interface and are termed as Gateway Candidate nodes. The IEEE 802.11(b) interface is, however, enabled on all MANET nodes. Among these gateway candidates, an optimal gateway must be selected using the node metrics of the Gateway Candidates such as residual energy, 3G Signal strength and the mobility speed.

The gateway issues such as mobility, depletion etc. need to be addressed, for which an Adaptive Gateway Migration Mechanism is proposed. When the optimality of the existing gateway is affected, a new gateway should be selected and the responsibility of the existing gateway should be migrated to the new gateway. With regards to gateway discovery mechanisms, as pro-active gateway discovery reduces delay and reactive discovery reduces overhead, this paper chooses a hybrid gateway discovery mechanism, combining the pro-active and reactive mechanisms. This requires configuration of parameters such as Gateway Advertisement Zone, in terms of TTL value, corresponding to the number of hops adaptively chosen from the Gateway and Advertisement Interval, the interval for which the GWADV messages should be broadcast within the advertisement zone.

## III. ADAPTIVE GATEWAY MANAGEMENT IN HWN

The Adaptive Gateway Management mechanism comprises of multi-metric Gateway Selection and Migration mechanisms. The Multi-metric Gateway Selection Algorithm (MGSA), used here, is based on the Simple Additive Weighting technique discussed by *Fudhiyanto Pranata Setiawan et al.* [6]. But, instead of using the number of hops from source to Gateway metric as in [6], this paper uses the 3G signal strength metric, measured in dBM, for the Gateway Candidate node, as the paper focuses upon the influence of the backbone network for Gateway Selection in MANET. However the other two metrics such as residual energy and mobility speed of the Gateway Candidates are used in this paper, as well. The scaling and normalization of metric values to non-dimensional values and computation of the net weights is as discussed in [6]. Here, a random source node initiates a Gateway Request (GWREQ) message within the MANET and the Gateway Candidates respond to the source node with their metric information. Then, an optimal Gateway is selected using the MGSA. And the active sources, at that instance, use this Gateway to communicate to the 3G network, unlike in [6], where active sources communicate to different Gateways, since hop distance from source was considered as a metric in Gateway Selection. Hence, the MGSA used in this paper prevents faster depletion of the Gateway Candidates.

### A. *Multi-metric Adaptive Gateway Migration mechanism*

The algorithm for Multi-metric Adaptive Gateway Migration mechanism (MAGMM) is shown in figure 2. It is focused to sustain the connectivity between the UMTS and MANET when either the residual energy of the Gateway or if the UMTS signal strength goes below the threshold value, which is 25% of the initial metric value of the Gateway Candidate. The Gateway seeks the metric information available from all the Gateway Candidates at that instance and computes the net scalable weight (Simple Additive weight) of the Gateway Candidates by the MGSA. It selects the Gateway Candidate with the maximum weight as the Gateway-Elect and forwards all new incoming transactions to it. The Gateway informs the current active sources of the Network about the Gateway-Elect using the hybrid Gateway Discovery mechanism, as discussed in [7]. The Gateway broadcasts the periodic GWADV within the advertisement zone, which is measured as number of hops from the Gateway, corresponding to the TTL value, adaptively selected from the Gateway. Here, the GWADV zone is configured to be half of the total number of hops in the MANET. And those MANET nodes, lying outside the GWADV zone, reactively broadcast Gateway Solicitation (GWSOL) messages within the MANET. And if such GWSOL messages reach any node within the GWADV zone, the GWADV is forwarded to them. It does not require the GWSOL messages to reach the Gateway to get information about the Gateway. This Hybrid Gateway Discovery mechanism reduces both the delay and overhead. The current Gateway completes the on-going transactions. After the current gateway completes its ongoing transactions, the 3G interface on the current Gateway is deactivated and the 3G interface on the new Gateway is activated to communicate with the UMTS backbone network. The new Gateway then proceeds with carrying on the Gateway responsibilities.

**Multi-metric Gateway Migration Algorithm:**

```
1.If((ENERGY of GATEWAY <
THRESHOLD_ENERGY) Or (SIGNAL_STRENGTH of
GATEWAY < THRESHOLD_SIGNAL_STRENGTH))Then
2.Call MGSA to select a new GATEWAY  and
name it GATEWAY_ELECT
3.Complete the on-going transmission and
forward all new incoming packets to
GATEWAY_ELECT
4.Use hybrid Gateway Discovery to inform
the MANET about the GATEWAY_ELECT
5.DEACTIVATE 3G interface on the GATEWAY
and ACTIVATE 3G interface on the
GATEWAY_ELECT
6.GATEWAY_ELECT sends ACK to GATEWAY.
7.GATEWAY becomes ACTIVE_SOURCE in the
MANET and GATEWAY_ELECT  becomes the
GATEWAY
8.End If
```

Fig 2 : Algorithm for Multi-metric Adaptive Gateway Migration

## IV. RESULTS AND DISCUSSIONS

The proposed Multi-metric Adaptive Gateway Management mechanism has been implemented in NS2.33 [8] in two phases. At the first phase, the Gateway Migration is focused only upon the energy metric, i.e. when the residual energy reaches a pre-defined threshold, the Gateway Migration mechanism is initiated. This phase is implemented so as to illustrate an effective Energy-efficient Adaptive Gateway Migration Mechanism (EAGMM), thereby, focusing upon the impact of residual energy. The second phase is MAGMM, which varies the priority factors of the other two metrics and studies the migration behaviour corresponding to the varied metric priorities. An integrated network comprising of 50 MANET nodes and the backbone UMTS Base Station Transceiver is simulated in a topography of 2200m x 500m. Each node in the MANET is configured with an initial energy of 25.0 J and an IEEE 802.11b interface, providing data transmission rate of 11Mbps. The Gateway Candidate nodes are additionally enabled with 3G UMTS Interface, simulated based on [9]. Random Way Point Model is used for generating the mobility speed of the nodes in the MANET. The backbone UMTS Network is configured for a peak uplink channel rate of 384 Kbps and downlink channel rate of 2 Mbps.

The HWN performance, implementing the proposed EAGMM and MAGMM is evaluated for Data Packet Delivery Ratio (DPDR), Transaction Duration (TD) and Control Packet Overhead (CPO), by varying the number of sources generating data packets. Transaction Duration is defined as the time taken between the commencement of the data packet transfer and the successful transmission of the last data packet in the HWN.

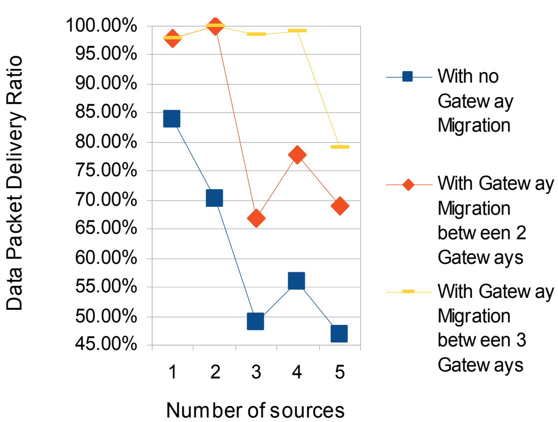


Fig 3 : Effect of Energy-efficient Gateway Migration on Data Packet Delivery Ratio against number of data sources

The graphs shown in Figure 3 and 4 evaluate the effect of Energy-efficient Adaptive Gateway Migration on DPDR and TD against the number of sources generating data packets. The graph indicates that the DPDR and TD show generally a negative trend to the increase in the number of sources generating data packets. The graph indicates that the need for Migration increases with multiple sources generating traffic as they result in faster depletion of the existing Gateway. EAGMM shows a 27.08% increase in DPDR and 15.31% increase in TD due to migration.

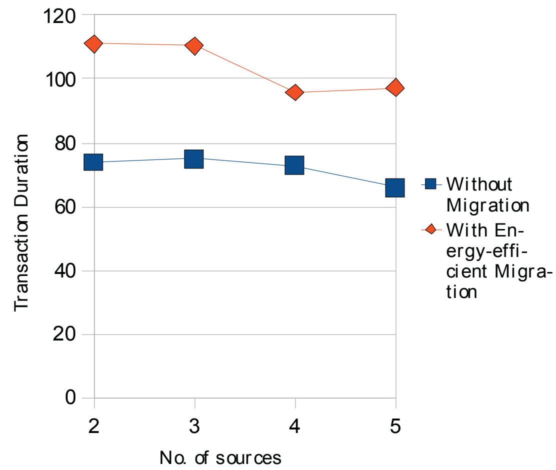


Fig 4 : Effect of Energy-efficient Adaptive Gateway Migration on Transaction Duration against the number of data sources

In the graph shown in figure 5, the effect of EAGMM is evaluated on CPO against the number of sources generating data. The graph indicates that the Control Packet Overhead shows a positive trend to the increase in the number of MANET sources. As the number of sources increase with a single Gateway, there arises network congestion due to high bandwidth consumption in the path to the Gateway. The number of packets dropped, error messages and subsequently, the control packets increase when there is more number of sources with no Gateway Migration. Thus, a need for migration increases. In the proposed method, when there is a migration, these control packets can be eliminated to a considerable extent as the traffic is balanced across the route to the newly-selected Gateways, thereby, effectively utilizing available bandwidth. However, there is some overhead involved due to migration. On the whole, EAGMM reduces the CPO by 31.5% than the overhead without migration.

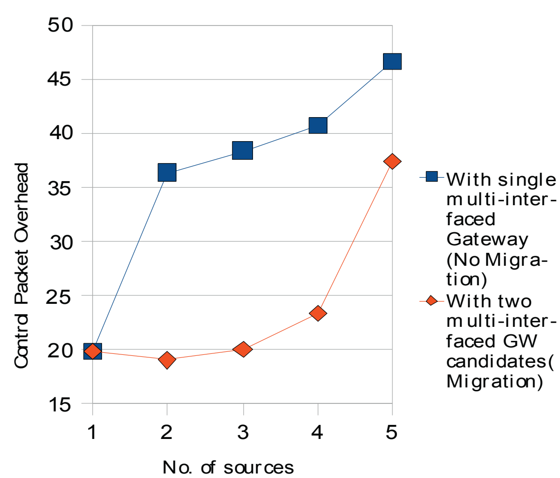


Fig 5 : Effect of Energy-efficient Adaptive Gateway Migration on Control Packet Overhead against the number of data sources

The Multi-metric Adaptive Gateway Migration (MAGMM) is analysed by varying the priority factors of every metric such as residual energy (α), 3G signal strength (β) and mobility speed (γ). Since multi-metric migration involves setting the priority factors and computation of scaled metric weights for mobility and energy metrics, the Network performances are not evaluated against the Mobility speed and Initial Energy of the gateway candidates. The weighting factors of the metrics provided by Direct Specification [6] are categorized as $W_1$, $W_2$, and W3. In $W_1$, the priority factors for the metrics are provided in such a way that the 3G Signal strength is given maximum priority value of 0.5, and the residual energy (α) and the mobility speed (γ) are given priority values of 0.2 and 0.3, respectively. In $W_2$, the priority factors for the metrics are provided in such a way that the mobility speed is given the maximum priority value of 0.5 and residual energy (α) and 3G signal strength (β), with priority values of 0.3 and 0.2. In $W_3$, equal priority value of 0.33 is given to all the three metrics. As an exhaustive energy-efficient Adaptive Gateway Migration has been simulated, there is no weighting factor in multi-metric Gateway Migration in which the residual energy is provided with the maximum priority.

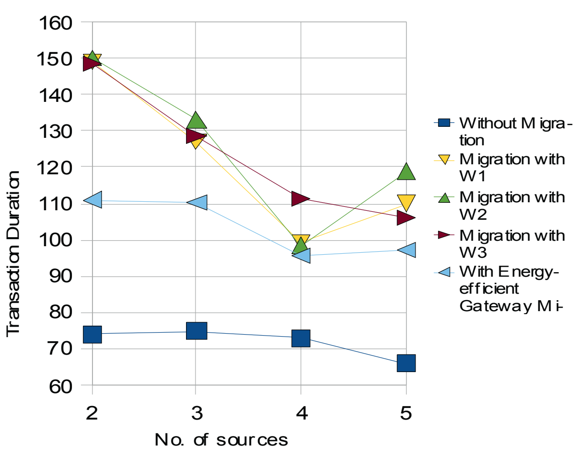


Fig 6 : Effect of Multi-metric Adaptive Gateway Migration on Transaction Duration against the number of data sources

In the graph shown in figure 6, the effect of Multi-metric Adaptive Gateway Migration is evaluated against the number of MANET sources generating data. As Migration sustains connectivity, the transaction duration as a result of multi-metric migration shows an enhancement over transaction duration due to energy-efficient migration by 23.5%. The effect of multi-metric Gateway Migration on Data Packet Delivery Ratio as a result of variation of priority factors of Gateway Metrics is shown in figure 7. With a similar reason attributed to the effect of energy-efficient Gateway Migration, stated as above, the need for Migration increases as the number of sources increase. As a result, MAGMM improves the Data Packet Delivery Ratio to a maximum of 2.08% than the DPDR computed by EAGMM. As a result of MAGMM, Network congestion, due to increasing the sources, is minimized by the process of migration of the responsibility to

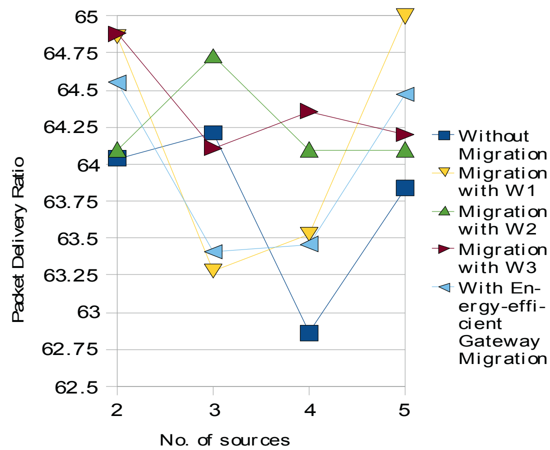


Fig 7 : Effect of Multi-metric Adaptive Gateway Migration on Data Packet Delivery Ratio against the number of data sources

a new Gateway, which would also contribute to effective utilization of bandwidth. With the inclusion of additional overheads due to migration, stated as reason for figure 5, the net control packet overhead is reduced by an average of 5% and a maximum of 11.09% than the CPO computed without migration by MGSA, as shown in figure 8.

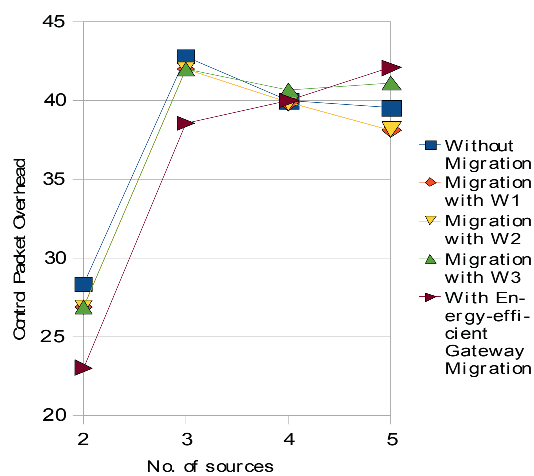


Fig 8: Effect of Multi-metric Adaptive Gateway Migration on Control Packet Overhead against the number of data sources

### *A. Comparison of the devised HWN architecture with the existing HWN Architectures*

The Multi-hop B3G architecture, devised in this paper, incorporating the Adaptive Gateway Management mechanism, is named as Adaptive Gateway Management-based Multi-hop B3G architecture (AGMMB3G) architecture. A comparison of AGMMB3G is carried out with the existing HWN architectures, detailed in [3], in terms of Operation Modes, Optimization goals, types of mobile user stations, support for multi-hop and out-of-coverage Mobile Stations, Gateway usage and Gateway Discovery. The Gateway Discovery scheme used in Ad hoc Global System for Mobile Communications (A-GSM) is pro-active, where Gateway nodes send beacon messages periodically within the Network. In Opportunity Driven Multiple Access (ODMA) Architecture, there is no concept of Gateway and every node can relay packets. The routing decision, here, is based on Signal strength. The Gateway nodes are deployed in planned positions in Integrated Cellular and Ad hoc Relaying (iCAR) systems and Gateway node has only single-hop support with respect to the Mobile nodes, within the network. In Unified Cellular and Ad hoc Architecture (UCAN), Mobile Nodes search for Gateway nodes only when their transmission rate decreases below a given threshold. The Gateway Discovery, used here, is either pro-active or reactive.

In two-hop relay architecture, the Gateway Nodes send periodic Gateway Advertisements and hence, the Discovery scheme is pro-active. Whereas in one- and two-hop direct transmission, the destination Mobile Nodes select the mode of connectivity, but they can also act as Gateways in case of failure of Access Points. In Hybrid Wireless Network Architecture, the Base Station selects the corresponding cell's mode of operation. Multi-hop Cellular Network (MCN) Architecture considers the Base Station to cover a minimum hop distance in the network of Mobile Stations, but does not consider the Gateway and the multi-hop support to it. The Base Station or Access Point selects the operation mode and executes a centralized routing algorithm. The architecture of Mobile-Assisted Data Forwarding for Wireless Data Network uses an ad hoc routing protocol for Gateway Discovery. In Self-Organizing Packet Radio Ad Hoc Network with Overlay (SOPRANO), MAC layer transmissions are directed to a node through several intermediate nodes by multi-hop and this routing decision is based on minimum interference on the channel and the node energy.

On comparison with the above architectures, AGMMB3G considers integration of Cellular (3G), WLAN and MANET networks. AGMMB3G supports dual-mode interface type for MANET Gateway Candidates and single-mode for the other nodes in the integrated HWN. Hybrid Gateway Discovery mechanism is used for Gateway Discovery mechanism due to which the delay and packet overhead required in discovering the Gateway is considerably reduced. As it uses the Adaptive Gateway Management mechanism to dynamically handle Gateways, the AGMMB3G optimizes over the other HWN architectures at sustaining interconnectivity between networks for a longer time, thereby enhancing the Transaction Duration. As a result, it also aims at improving the Data Packet Delivery Ratio, Control Packet Overhead and support for Multi-hop and out-of-coverage Mobile Nodes.

## V. CONCLUSION AND DIRECTIONS FOR FUTURE RESEARCH

An Adaptive Gateway Management mechanism is discussed and a multi-hop B3G architecture AGMMB3G, incorporating the Adaptive Gateway Management, is devised in this paper. The Multi-metric Adaptive Gateway Migration Mechanism (MAGMM), in Adaptive Gateway Management, comprising of Gateway Selection and Migration Mechanisms, to sustain Gateway connectivity with the external UMTS network for a longer time, is discussed. Simulations have been performed in ns2, detailed in [8]-[10], and EAGMM and MAGMM enhance the HWN performance in terms of Transaction Duration, Data Packet Delivery Ratio and Control Packet Overhead parameters. As future work, the research shall be extended to propose a polymorphic end-to-end routing protocol, integrating the multi-hop reactive routing mechanism in MANET, pro-active routing mechanism in UMTS backbone network and single-hop packet forwarding in WLAN. Further, Quality of Service (QoS) in HWN routing can be enabled for multimedia data transfer. In addition, group communications in heterogeneous wireless networks need to be exhaustively studied for multicasting within Heterogeneous Wireless Networks.

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