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Adaptive Gateway Management in Heterogeneous Wireless Networks

R. Manoharan, E. Ilavarasan and S. Rajarajan

Department of Computer Science and Engineering, Pondicherry Engineering College, Puducherry, India

Email: rmanoharan@pec.edu

Abstract - In the recent years, there exist an ever-growing demand for ubiquitous connectivity which requires seamless integration of Mobile Ad hoc Network, Wireless LAN and Cellular networks. Integration of these networks results in a heterogeneous wireless network (HWN) architecture which is capable of providing high data-rate, end-to-end connectivity utilizing the higher bandwidth of multi-hop networks and the wide range communication of 3G Networks. HWN architecture has numerous real-world applications such as communication between spatially-apart military troops in war-front, disaster recovery operations which demand data access from heterogeneous networks. To provide seamless connectivity in HWN architecture, gateway nodes are required in MANET and WLAN to liaison with the cellular network for data communication. In this paper, an Adaptive Gateway Management (AGM) which includes an effective gateway selection mechanism to select an optimal Gateway from the Gateway Candidate Nodes, is proposed using metrics such as residual energy, 3G signal strength and mobility speed. Once a selected gateway loses its optimality due to diminishing energy and dynamic changing topology, makes it unavailable which results in disconnection between networks. In order to sustain the connectivity between networks for a longer time, an Adaptive Gateway Migration mechanism has also been proposed to select an optimal gateway to which the responsibility of the current gateway is migrated, when the above metric values reach to a predefined threshold. This adaptive gateway management scheme has been implemented in a HWN environment using Network Simulator 2. Extensive simulations have been carried out and the results show that the proposed scheme enhances the overall performance in terms of packet delivery ratio, transaction duration and control overhead.

Keywords – HWN Architectures, Adaptive Gateway Management, Seamless Connectivity

1. Introduction

Recently heterogeneous networks have become major research topic in wireless networks which integrates multiple wireless systems to provide anywhere anytime data access and connectivity. The development of WLAN (e.g. IEEE 802.1 a/b/g/e/h/i) combined with Wireless Wide Area Network (WWAN) (e.g. 2G, 2.5G, 3G) and the Internet can provide a ubiquitous environment providing faster data rates, reliable transmission in different environment. Mobile Ad Hoc Network (MANET), as a model of infrastructure-less network, is easy to install, self-configurable and economically extend the boundaries of any terrestrial network. MANET has numerous applications such as situational awareness system in military, disaster recovery operation and wireless home and office area networks. Many of these applications require a global ubiquitous connectivity to access data from other remote networks and communication within MANET. On the other hand, the 3G cellular networks such as UMTS [7] offer wide area wireless connectivity whose signals are available almost everywhere, but it provides only limited data rate. In this paper, to achieve ubiquitous connectivity and to improve the overall performance of the system, an architecture integrating MANET, WLAN and 3G cellular network (UMTS) is proposed.

The rest of the paper is organized as follows: In section 2, the review of the existing literature is presented. Section 3, introduces the proposed heterogeneous architecture. Section

4, describes the gateway selection ad migration algorithms. It also presents the normalization procedure to identify and select the optimal gateway to enhance the gateway performance. Section 5, present the extensive simulation results. Finally, the concluding remarks are given in section 6.

2. Review of Literature

Different types of heterogeneous network architectures have been proposed in [6]. In [1], architecture for connecting ad hoc networks with Internet backbone which uses a wireless Gateway has been proposed. This gateway node maintains a wireless connectivity with an access point (AP), which is in turn connected to a wired internet backbone. But, in a real time scenario such as at warfronts, disaster areas a wired internet connectivity cannot be relied upon.

In [2], a new architecture called 'Unified Cellular and Ad hoc Network Architecture' (UCAN) is proposed. It aims at providing high data rate services to mobile clients which are in low bandwidth cellular region by deploying MANET nodes as proxy clients who receive high intensity cellular signals. The cellular network considered here is CDMA which provides low data rate services.

In [3], an Effective Gateway Discovery in Hybrid Wireless Networks (HWN) is illustrated by the Adaptive Distributed Gateway Discovery (ADD) mechanism. This method combines the reactive and pro-active approaches of Gateway discovery. It defines a transmission range where the Gateways periodically send Advertisement messages (GWADV) and they are propagated around a limited zone, at a certain number of hops away from the Gateway. This hop distance is corresponding to the TTL value, adaptively selected by the Gateway. In this, the Gateway is static without considering any metric and Gateway discovery Mechanism is only focused upon.

An optimum multiple metric gateway selection mechanism is proposed in [4] considering the metrics for selection: remaining energy, mobility and number of hops for interconnecting MANET with infra-structured network. In this paper the author has considered every MANET to possess different Gateway node to interconnect with infrastructure network. Also, the metrics are not chosen based on the nature of the infrastructure network.

In the existing literature, ubiquitous connectivity to MANET has not been fully explored. The gateway interconnecting MANET is usually static and is connected to the wired backbone. Additionally the gateway in MANET are selected based on local metric such as energy, hop distance, etc., and doesn't consider any metric such as signal strength , channel rate, etc., concerning the backbone network which is required for ubiquitous connectivity. None of the existing architecture combines WLAN, MANET and 3G cellular network.

3. Proposed Heterogeneous Architecture

The main objective of the HWN is to integrate various wireless network models namely MANET, WLAN and 3G which provides seamless connectivity and end-to-end data transfer between different networks operating under different environment. The proposed architecture consists of nodes in groups connected in two modes, Infrastructure mode (single-hop), where connectivity is provided through AP and MANET mode, where communication between nodes is through multi-hop routing as shown in Figure 1. In order to establish connectivity between different network models, we need a ubiquitous backbone network and dual-interface nodes interconnecting the group and backbone network. The backbone network considered here is UMTS (3G cellular network), offers a wide range of communication with a peak downlink data rate of 2 Mbps and an uplink data rate of 384 Kbps. The main components of the UMTS network 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 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. This backbone network is used for establishing ubiquitous connectivity and data transfer between spatially-apart MANET and WLAN groups.

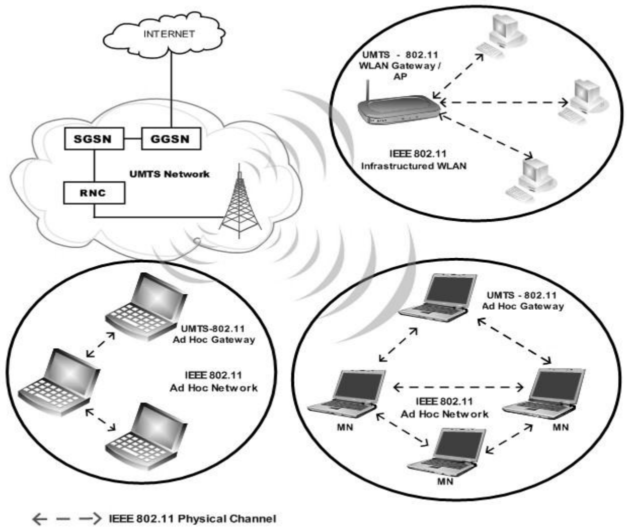

Figure 1: Architecture of Heterogeneous Wireless Network System

To liaison MANET, WLAN and the backbone network dual-interface nodes which are equipped with 3G cellular interface and IEEE 802.11b interface is employed here. These dual interface nodes are also called Gateway Candidates (GC).When nodes are connect in MANET mode, one among the dual interface nodes in the group must act as a gateway interconnecting MANET and backbone network for seamless integration and to enable end- to-end connectivity. An optimal gateway is selected from these gateway candidates.

Additionally the gateway node has to meet certain requirements such as availability, reliability and enhanced connectivity which helps to provide end-end data transfer. Hence, an AGM mechanism is proposed which includes an efficient multi-metric gateway selection algorithm to enhance connectivity between networks and an efficient single metric migration to sustain the connectivity between networks for a longer time.

4. Adaptive Gateway Management

The following section includes detailed description of two components of AGM mechanism viz. gateway selection and migration algorithms.

4.1. Gateway Selection Algorithm

The Gateway Selection Algorithm (GSA) proposed here is based on metrics such as mobility speed, remaining energy of the GC and signal intensity of the UMTS backbone network. The selected gateway must be able to enhance connectivity a provide service for a longer time. So, the GC which is selected as the current gateway should have higher remaining energy. Additionally in a real-time environment, the intensity of UMTS network signal is not uniform across a region and it varies from place to place. This signal intensity, also called signal strength is measured in terms of dBM. A node witnessing higher dBM value will get higher bandwidth from the UMTS network and vice-versa. Since MANETs are infra-structure less, their nodes have the privilege to be mobile in any environment. But the GC which is selected as gateway must be present in high signal intensity region of the backbone network for availing high data-rate services. To satisfy all these constraints, the selected gateway should have high remaining energy, less significant mobility and is expected to be in high signal intensity region of backbone network when compared to other GC.

The metric values fall in different ranges and have different scales of evaluation. Hence, these values are scaled and brought into non-dimensional values. This scaling method is of two types. The first one is for metrics with positive criteria and the second one for metrics with negative criteria. The criteria for remaining energy and signal strength metric is positive because having higher value for these metrics will make the interconnection of networks to last long with high data rate service. Whereas, criteria for mobility is considered to be negative as increase in mobility will lead to routing overhead and congestion which decreases the throughput and performance of the network. All the metrics considered are scaled to uniform value between 0 and 1 by applying the following equation:

If (criteria==“positive”) , $Y = \frac{X - X_{\min}}{X_{\max} - X_{\min}}$

Else if (criteria==“negative”), $Y = \frac{X_{\max} - X}{X_{\max} - X_{\min}}$

End if

(1)

where ‘X’ is the value of each metric, Xmin and Xmax are corresponding minimum and maximum value of metrics considered, among all the GC. Scaled values are then weighted based on the priority given to each metric. Weight is the preference or priority given to each metric out of 1 and hence the sum of weights is always equal to 1. The total additive weight of a GC is calculated by the equation:

$$W = \sum_{i=0}^{n} (\text{weight for individual metric} * \text{scale metric value}) \quad (2)$$

where n is the total number of metrics.

In the proposed algorithm, a random node in MANET initiates the Request for Selection of Gateway among the GC, by broadcasting the gateway request (GREQ) packet to all the nodes in the MANET. Gateway candidates respond to this GREQ packet by sending their metric information via hello packets. On receiving these reply hello packets, the initial node extracts the metric information and selects the best GC having the highest value calculated by (2), as the current gateway for MANET.

Next, the information about the newly selected gateway is transmitted to all the nodes in the MANET. All the nodes update the new gateway information in their routing tables and will use the same for all future communications with the external network. The dual interface on the newly selected gateway is then activated and it takes over all the communications to the external cellular network.

<u>Algorithm for Gateway Selection</u>

1. Broadcast GREQ to all nodes of the MANET
2. If (status = MANET node) then
3. broadcast GREQ message
4. Else if (status = GATEWAY CANDIDATE) then
5. Reply via HELLO with metric information
6. End if
7. SCALE metric values of each GC using equation (1)
8. Calculate W of each GC using equation (2)
9. NEW_GATEWAY= Max (W)
10. Broadcast HELLO with NEW_GATEWAY to all nodes in MANET
11. ACTIVATE dual interface of NEW_GATEWAY

4.2. Gateway Migration Algorithm

The Gateway Migration Algorithm (GMA) proposed here is relatively simple and is used to keep the interconnection of heterogeneous networks alive for a longer period, by maintaining an efficient Gateway. i.e. If the current gateway is predicted to get depleted and out of action in a few moments, then the GMA searches for a new Gateway and transfers the roles and responsibilities of the current Gateway to the newly selected Gateway, before the current Gateway depletes completely. By this, the function of the Gateway in the MANET is sustained without any interruption due to the depletion of the current Gateway.

4.2.1. Energy-Efficient GMA

Energy-Efficient GMA periodically checks and monitors the energy value of the current Gateway. If the energy value falls below or reaches the threshold value which is 25% of initial energy, the algorithm immediately executes the GSA to begin the process of search of new gateway. Once, the new gateway having optimum metric value is found and returned by the selection algorithm, all the roles of the current gateway are transferred to new gateway.

<u>Algorithm for Energy-Efficient Gateway Migration</u>

1. If (Energy [CURRENT_GATEWAY]<= THRESHOLD)
2. Call GSA
3. Forward all incoming connections to NEW_GATEWAY
4. DEACTIVATE dual interface on the CURRENT_GATEWAY
5. CURRENT_GATEWAY = NEW_GATEWAY
6. End if

4.2.2. Multi-metric GMA

The working of multi-metric GMA is similar to that of energy-efficient GMA except that it checks for threshold values of all the metrics concerning MANET (Energy of the GC) and UMTS backbone (signal intensity).

<u>Algorithm for Multi-metric Gateway Migration</u>

1. If (Energy [CURRENT_GATEWAY] <= THRESHOLD || Signal_Intensity[UMTS] <= THRESHOLD)
2. Call GSA
3. Forward all incoming connections to NEW_GATEWAY
4. DEACTIVATE dual interface on the CURRENT_GATEWAY
5. CURRENT_GATEWAY = NEW_GATEWAY
6. End if

In the transformation process, all the new incoming connections are forwarded directly to the New Gateway. All the current ongoing transactions using the current Gateway are not disturbed and the GMA waits for their completion. When all the current transactions are completed, the dual interface on the current gateway is deactivated and is released. Then, the new Gateway takes charge as the current Gateway and continues its operation as Gateway to the MANET.

5. Results and Discussions

The proposed AGM mechanism has been implemented in NS2.30 [9, 11]. An integrated Network comprising of 50 MANET nodes and the backbone UMTS Base Station Transceiver is simulated in topography of 2200m x 500m. Each node in the MANET provided with an initial energy of 25.0 J is enabled with IEEE 802.11b interface, providing data transmission rate of 11Mbps and support AODV routing protocol [10]. The Gateway Candidate nodes are additionally enabled with 3G UMTS Interface [8]. The proposed work assumes only those nodes lying under the UMTS signal strength as Gateway Candidates. The mobility speed of the Gateway Candidate nodes is varied till a peak velocity of 25ms-1. The backbone UMTS Network is configured for a peak uplink channel rate of 384 Kbps and downlink channel rate of 2 Mbps [5].

The HWN performance, implementing the proposed AGM mechanism is evaluated in terms of metrics such as Data Packet Delivery Ratio, Transaction Duration and Control Packet Overhead, by varying the mobility speed, Initial Energy of the gateway candidates and 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. The ratio of the number of data packets received to the number of data packets sent, in terms of percentage is termed as the Data Packet Delivery Ratio, and Control Packet Overhead is measured as the ratio of the total number of control packets and acknowledgement signals generated as against the total number of packets sent from the source. Extensive simulations were carried out for analysis of results and each data point in the graphs is averaged out of multiple simulation trials.

In the graph shown in figure 2, number of sources generating data packets is increased for each trial of a constant number of multi-interfaced GC. The graph indicates that the Data Packet Delivery Ratio shows a negative trend to the increase in the number of sources generating data packets. The graph shows that increasing the number of Multi-interfaced GC and performing energy-efficient migration among them increases the Data Packet Delivery Ratio, on an average, by 27.08%. The graph shown in figure 3 evaluates the effect of Gateway Migration on Packet Delivery Ratio of data packets generated from multiple sources against the mobility speed of the GC. The graph indicates that as the mobility speed of the GC increase, the need of Gateway Migration also increases as the speed is considered as a Negative criterion to measure optimality of the Gateway. The Energy-efficient Migration mechanism shows an increase in the performance of Data Packet Delivery Ratio by 3.12%.

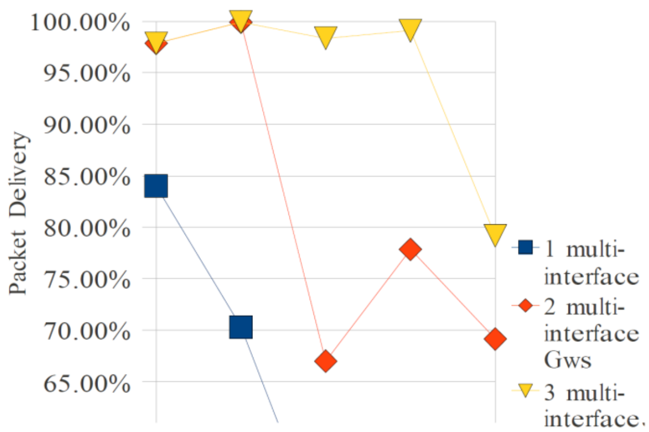

Figure 2: No. of sources (Vs) Data Packet Delivery Ratio with constant number of multi-interfaced Gateway Candidates

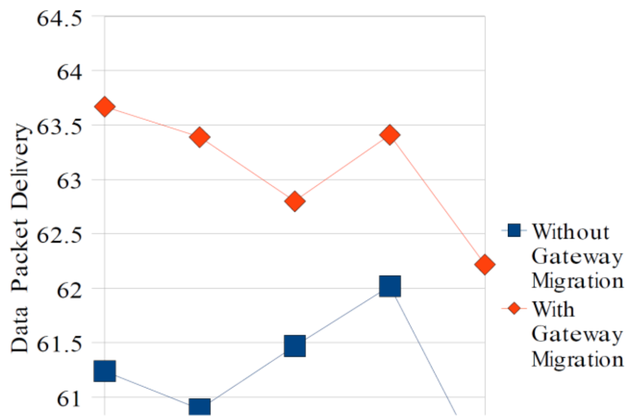

Figure 3: Effect of Migration of Mobile Gateways on Data Packet Delivery Ratio

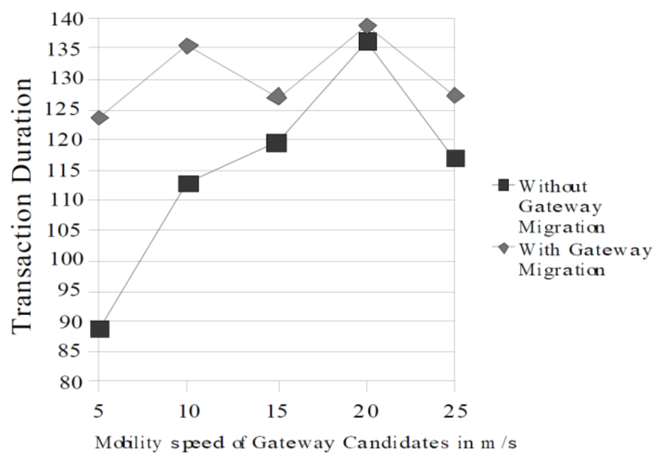

Figure 4: Effect of Mobile Gateway Migration on Transaction Duration with multiple sources

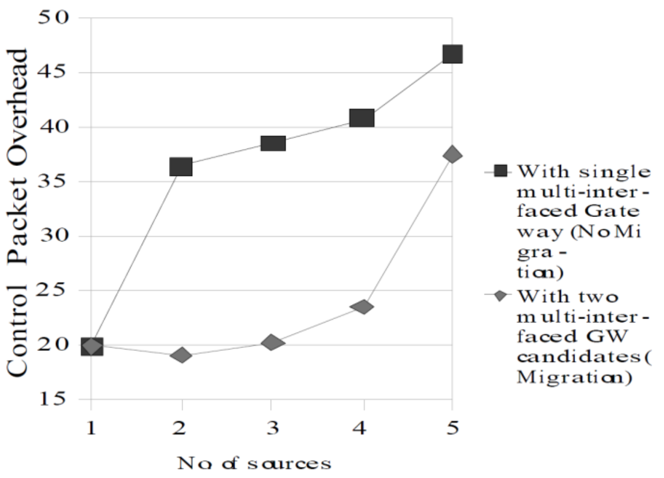

Figure 5: Effect of no. of sources on Control Packet Overhead

The graph shown in Figure 4 uses multiple sources, generating data packets. The graph indicates that the need for Migration increases with multiple sources generating traffic and with increase in the mobility speed of the GC. Thus, the energy-efficient Gateway Migration mechanism shows an average of 15.31% increase in the Transaction Duration. In the graph shown in Figure 5, the control packet overhead is evaluated by increasing the number of sources generating data packets, for each trial of constant number of GC. The graph indicates that the Control Packet Overhead shows a positive trend to the increase in the number of MANET sources. The Control Packet Overhead shows a positive trend to the increase in the mobility speed, which is categorized as a negative criterion in the Selection algorithm, and thus, a need for migration increases. 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 and subsequently, the control packets increase when there is more number of sources with a single Gateway. In the proposed method, when there is a migration, these control packets can be eliminated. However, there is some control packet overhead involved in the Migration. The graph shows that increasing the number of Multi-interfaced GC and performing energy-efficient Migration among them decreases the CPO by 31.5%.

In the graph shown in Figure 6, the Control Packet Overhead is evaluated with the increase in the Mobility speed of the GC with the MANET nodes. The Control Packet Overhead shows a positive trend to the increase in the mobility speed and thus, a need for migration increases. With similar reasons attributed to the graph shown in Figure 5, upon Energy- efficient Gateway Migration, the Control Packet Overhead is decreased by 17.31%.

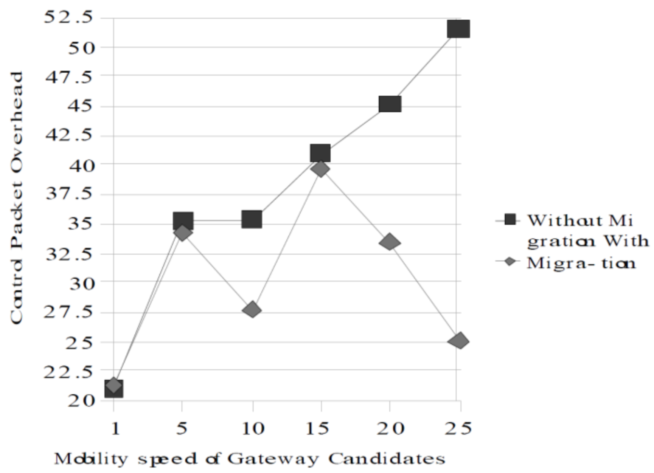

Figure 6 : Effect of Mobile Gateway Migration on Control Packet Overhead with multiple sources

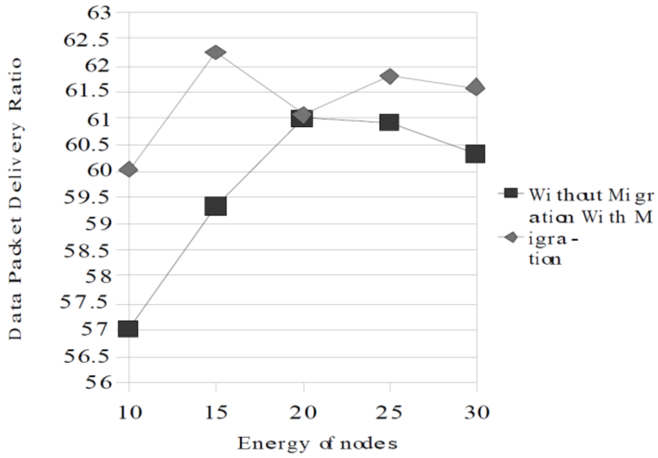

Figure 7: Effect of Energy-efficient Gateway Migration on Data Packet Delivery Ratio

The graphs shown in Figures 7 and 8 evaluate the Data Packet Delivery Ratio and Control Packet Overhead against the increase in the energy of MANET nodes, keeping the mobility speed of the GC constant. As speed is a negative criterion in the optimality of Gateway selection, increase in speed has a negative impact on Data Packet Delivery Ratio and a positive impact on Control Packet Overhead. Hence, the graphs indicate an increase in the Data Packet Delivery Ratio by 2.77% and a decrease in CPO by 28.75%, on an average, as a result of energy-efficient Gateway Migration.

In the graph shown in figure 9, the effect of energy-efficient Gateway Migration on Transaction Duration is evaluated against the initial energy of the MANET nodes. It is quite obvious that as the initial energy of the MANET active sources are increased, the transaction duration increases. But the effect of Energy-efficient Gateway Migration is more as the initial energy of the MANET nodes increases, because the threshold value of the energy metric (50%) increases subsequently. So, this increases the need for migration with increase in the initial energy. Energy-efficient Gateway Migration shows an average of 5.5% increase in Transaction Duration. Similarly, the graph in figure 10 evaluates the effect of energy-efficient Gateway Migration on Transaction Duration against increasing number of MANET sources, generating data packets. Migration enhances the network performance in terms of Transaction Duration over the normal scheme without Migration by a minimum of 31%.

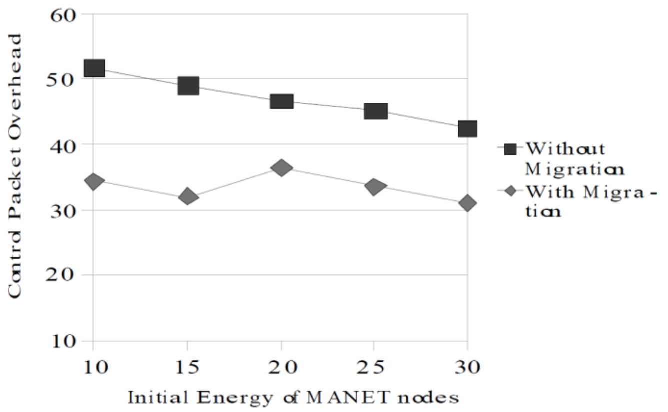

Figure 8: Effect of Energy-efficient Gateway Migration on Control Packet Overhead against initial energy of Gateway Candidates

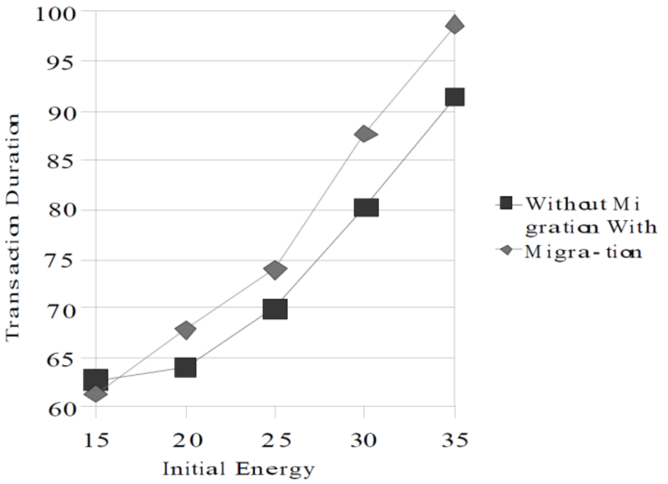

Figure 9: Effect of Energy-efficient Gateway Migration on Transaction Duration against Initial Energy of Gateway Candidates

The proposed GSA and the adaptive multi-metric GMA mechanism are implemented and their effect on transaction duration, Data Packet Delivery Ratio and Control Packet Overhead are calculated against the number of MANET sources. The multi-metric Gateway Migration is analyzed by varying the priority factors of every metric such as residual energy (á), 3G signal strength (â), inversely proportional to the distance between Gateway and the UMTS BST, mobility speed (ã), that is considered, normalized and brought to a scalable value. 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 GC. The weighting factors of the metrics are categorized as W1, W2, W3. In W1, the priority factors for the metrics are provided by Direct Specification [4], in which 3G signal strength is given maximum priority. In W2, the priority factors for the metrics are provided in such a way that the mobility speed is given the maximum priority and in W3, equal priority values are 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.

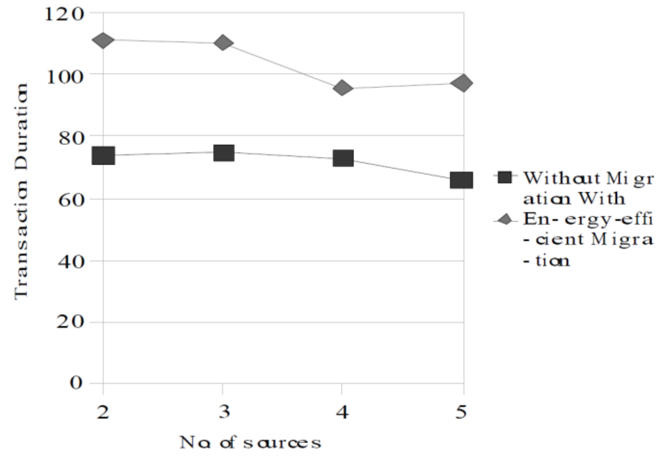

Figure 10: Effect of Energy-efficient Gateway Migration Transaction Duration against number of MANET sources

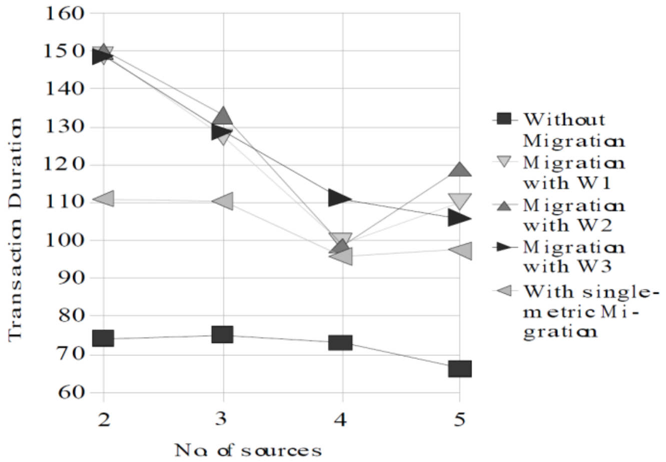

Figure 11: Effect of Multi-metric Gateway Migration on Transaction Duration against number of MANET sources

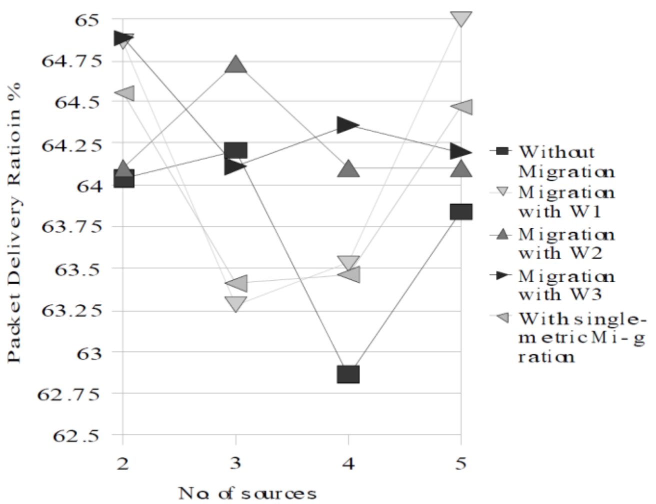

Figure 12: Effect of multi-metric Gateway Migration on Packet Delivery Ratio

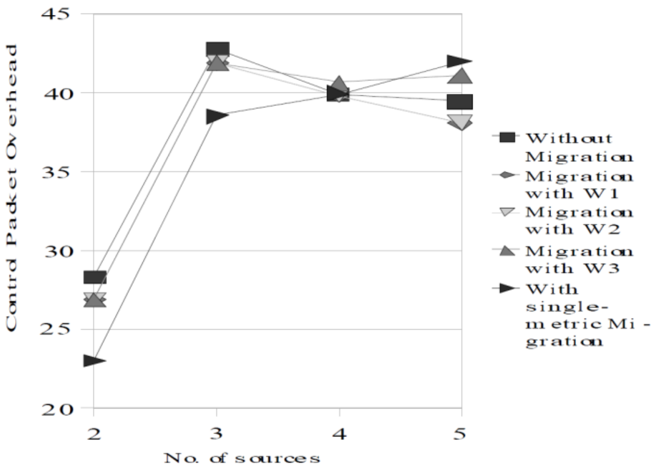

Figure 13: Effect of multi-metric Gateway Migration on Control Packet Overhead

In the graph shown in Figure 11, 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 as a result of variation of priority factors of Gateway Metrics is shown in Figures 12 and 13 As a result, multi-metric Gateway Migration improves the Data Packet Delivery Ratio to a maximum of 2.4% than the PDR computed by GSA. 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. As a result of multi-metric Gateway Migration, Network congestion, due to increasing the sources, can be minimized by migrating the responsibility to a new Gateway, which would also contribute to effective utilization of bandwidth. With the inclusion of overheads due to migration, the net control packet overhead is reduced by an average of 5% and a maximum of 11.09% than the Control Packet Overhead computed by GSA.

6. Conclusion

This paper explains the need for heterogeneous Wireless Networks for seamless data access. The Gateway issues in HWN have been analyzed and an Adaptive Gateway Management (AGM) Mechanism has been devised, comprising of Gateway Selection and Migration Mechanisms. The energy-efficient and multi-metric mechanisms are the two mechanisms involved in Adaptive Gateway Migration and they have been elaborately discussed. Simulations have been performed in ns2 and AGM enhances performance of Transaction Duration, Data Packet Delivery Ratio and Control Packet Overhead metrics. As future work, a polymorphic end-to-end routing, integrating the reactive routing mechanism in MANET and pro-active routing mechanism in UMTS and WLAN, shall be devised.

Acknowledgements

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