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Performance Analysis of Coexistent Heterogeneous Networks for various Routing Protocols using Qualnet Simulation

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Abstract— **As the explosive growth of the ISM band usage continues, there are many scenarios where different systems operate in the same place at the same time. One of growing concerns is the coexistence of wireless systems. In heterogeneous networks, mobility, traffic and node density are main network conditions that significantly affect the performance of routing protocols. Much of the previous researches in homogeneous routing have focused on developing strategies, which suit one specific networking scenario. Therefore, there is no existing protocol that can work well in all different networking scenarios. This paper reviews characteristics of each different classes of routing protocols. Moreover, most of current routing protocols assume homogeneous networking conditions where all nodes have the same capabilities and resources. Although homogenous networks are easy to model and analysis, they exhibits poor scalability compared with heterogeneous networks that consist of different nodes with different resources. This paper presents extensive studies simulations for AODV, DSR, LANMAR, LAR1 and FSR in homogenous and heterogeneous networks. The results showed that these which all protocols perform reasonably well in homogenous networking conditions, their performance suffer significantly over heterogonous networks. Further this paper presents the mobility model for the heterogeneous network for different interference size.**

Index Terms—**Coexistence, Heterogeneous Networks, Interference, Routing protocol.**

I. Introduction

Because of the mobility and ubiquitous deployment of wireless systems, there are many scenarios where different systems operate in the same place at the same time. Hand-held PDA can use a Bluetooth device to connect to a laptop with 802.11b WLAN.

Many routing protocols have been proposed to mange the communication on this kind of networking. Moreover, there are many issues that must be considered in constructing any routing protocol such as power consumption, reliable data delivery, and overheads and delays. Recent work on MANET routing protocols have focused on achieving stability and reliability to reduce packet loss, communication overheads, and to increase data delivery ratio. Different approaches have been proposed to achieve those goals. Some of those focused on improving physical layer to provide reliable transmission, like diversity techniques, coding and Single Path Parallel Relays (SPPR) strategies [1-3]. Cooperation between link layer and network layer was another approach [3], where the state and the availability of the link on link layer were analyzed before calculating the routes [3].Others expanded the existing protocols like AODV, LAR, and DSR by implementing the multipath strategy [4, 5].

However, mobility of the nodes has not been the main focus of those papers. We anticipate that several problems in MANETs arise due to the mobility such as high data delay and low packet delivery ratio. Hence, node mobility has to be considered in order to achieve high stability and reliability. Different strategies have been implemented in [6-8] to satisfy different degrees of mobility. On the other hand, most existing routing protocols have not been able to satisfy both scalability and mobility. Many routing strategies have been proposed to improve the performance of existing protocols or design new ones to deal with mobility or node density. In [8], Adaptive Cell Relay routing protocol (ACR) has been designed to deal with different density degree of the nodes to achieve high scalability. It uses two different routing strategies: the cell relay (CR) routing for dense networks, the large cell (LC) routing for sparse networks. It also monitors the node density changes to determine which routing strategy to apply according to the network density. A routing framework has been proposed in [6] to work on different mobility classes that are low, normal and fast. Mobility class was calculated using the proposed mobility metric referred to as "Stability". Stability is based on associability that is defined as a time where the node can communicate with other nodes, and according to the stability value, a protocol is selected to route the packet. If a node is classified to be slow then a proactive protocol, like DSDV, will be used, if mobility class is normal then a reactive protocol like AODV will be applies, and the introduced RUNNER protocol will route the data if the mobility class is fast. In [9], two new protocols have been proposed to work with high mobility nodes in MANET. The idea behind these two protocols is that there is a group of mobile nodes which move throughout the entire network to receive and deliver data and control messages. These nodes are called the support nodes. One of the protocols is called Snake where the support nodes are predefined and then a leader election is carried out. The leader manages the movement of its group of support nodes in a form of snake movement. While each support nodes in

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RUNNER (second protocol) moves independently like a runner. However, the idea of support protocols cannot be applied in homogenous systems. Support nodes should have more capabilities and resources.

Few comparisons between different existing protocols have been published such as in [10, 11]. For example, in [10],AODV protocol and RUNNNER protocol have been evaluated. It has been found that AODV has higher data delivery ratio and lower data delay in dense network and low mobility of nodes. This is because AODV can reach destinations easily in such network conditions. On the other hand, RUNNER performs better in high mobility network where the support nodes are faster in delivering data. In [11], DSDV, AODV, and DSR have been compared in different scenarios of nodes mobility and traffic loads. The simulation results showed that reactive protocols (DSR and AODV) performed better than proactive protocols when nodes were moving. In addition, DSR works well with low traffic while AODV behaves better in higher traffic. A probabilistic model has been proposed in [12] to evaluate overhead of routing protocols of MANET. This model depends on network topology and data traffic parameters to estimate the number of control packets. In addition it can help identifying a protocol for particular situation. This model was tested by comparing it with existing simulations of AODV, DSR, and OLSR. Reactive protocols again performed better than proactive protocols when the mobility increases.

Most of current routing protocols assume homogeneous network conditions where all nodes have the same capabilities and resources. Although homogenous network are easy to model and analysis, they exhibits poor scalability compared with heterogeneous networks that consist of different nodes with different resources. Heterogeneous MANET comprise of mobile devices as Fig.1 that have different communications capability such as radio range, battery life, data transmission rate, etc.

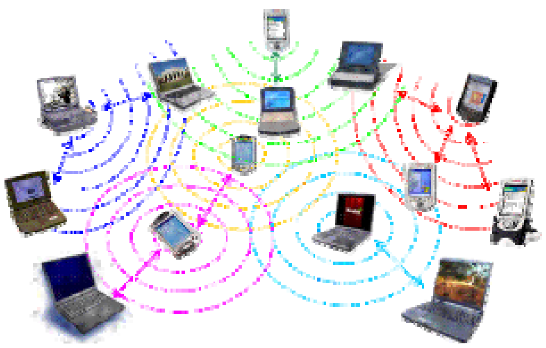

Fig.1.Heterogeneous Network System.

Moreover, in real world, some of MANET networks are obviously heterogeneous like military battlefield networks and rescue operations system. For instance, in a rescue operations system, there are limited mobile devices that are provided to individual rescuers, ambulances and police vehicles, and helicobacter. Limited mobile devices have lowest communication capabilities, while helicobacter is the most powerful communication device which forms backbone of the rescue team. Therefore, heterogeneity of nodes is another issue that needs to be considered in constructing and developing routing protocols for MANETs.

Recently, a few publications have introduced some strategies to develop routing protocols to accommodate heterogeneous MANETs.

On-demand Utility-Based Routing Protocol (OUBRP) strategy has been proposed in [13] to develop reactive routing protocols to efficiently utilize the heterogeneity of nodes. A utility-based route discovery algorithm is used to choose the richest nodes with highest level of resources during route discovery stage. The utility level of resources is reduced, if the route was not found. OUBRP reduces the number of re-broadcasting nodes. This strategy has been implemented over AODV. It has been found that this strategy improves routing discovery and reduces effect of route failure. In [14], scalability issue of OLSR in heterogeneous MANET has been studied. The study show that OLSR it does not differentiate distinct nodes with different communication capability and resources. This paper proposed a strategy to optimize OLSR to be scalable over large heterogeneous MANET. OLSR was improved by organizing nodes in hierarchal structure. Hierarchal OLSR (HOLSR) has eliminated overheads and reduces the size of routing table. With HOLSR, the nodes are organized in logical level, where nodes with lowest resources are in lower level. Each level has many clusters, where the cluster head is a powerful node with highest communication capability. HOLSR and flat OLSR have been compared in terms of control overhead, computations overhead, and end-to-end delay. HOLSR shows significant improvement to the performance of OLSR. Also it performs well in large heterogeneous MANET.

A new routing protocol was proposed in [15] to make use of heterogeneity in MANET. The entire network area was divided into cells with same size. The most powerful node in a cell acts as a gateway, where most the routing load goes through. This powerful node is called B-node. All B-nodes form the backbone of the entire networking. B-nodes reduce number of hops because they have high communication capability to transmit data.

Heterogeneous MANETs have the potential of reducing the amount of power used at user nodes. In [16] author state that supply of power in heterogeneous wireless ad hoc networking can affect the lifetime of network. They proposed a cross- layer for Device Energy-Load Aware Relaying (DELAR) strategy to utilize powerful nodes. This strategy suggested having a schedule to use different transmission powers in different periods. They also proposed "mini-routing" and Asymmetric MAC (A-MAC) to support link level acknowledgements with unidirectional links. The simulation of DELAR showed that this strategy can reduce power consumption and increase lifetime of network.

The common approach to dealing with heterogeneity of nodes in previous papers [13-15] is to assign most of the routing load for the powerful nodes, as they possess more resources and communication capabilities. Consequently, this approach eliminates number of hopes and can reduce delay. However, this strategy may create critical problems if the powerful nodes go off-line.

Up to now, several reviews have been published which described the functionality and theoretical performance of

MANET routing protocols. For example, in [17, 18] routing protocols for MANETs have been revised and classified according their scalability. However, no study has attempted to evaluate the performances of current routing protocols in heterogeneous networks. In this paper, different classes of MANET routing protocols are reviewed. A suitable class of routing protocols is suggested to perform well in a particular network conditions. Additionally, the performances of AODV, DSR, LANMAR, LAR1 and FSR are compared by simulating them in homogenous and heterogeneous coexisting network.

The performance of these protocols is analyzed in section two. Section three describes our simulations of different protocols in homogenous and heterogeneous network. Section four discusses our results. Last section concludes this paper.

II. Comparison Of Different Classes Of Routing Protocols For Manets

In this section, comparison of proactive, reactive and hybrid protocols is outlined by combining their published theoretical performance [19] [12]. That comparison is further verified through the published simulation results [6, 11, 19-22]. Based on that comparison, a suitable class of routing protocols is suggested to perform well in a particular network conditions.

A. *Theoretical and model based analysis*

Proactive protocols are the oldest protocols that have been derived from wired network routing protocols to work in the wireless environment. Therefore, they possess many features of wired routing protocols like routing tables that are used to keep the routing information, which are periodically updated even if not needed. As the node moves, there is a flooding of packets containing the topology changes causing high overheads. Hence, in general, proactive protocols produce more overheads resulting in a lower throughput in case of high mobility as illustrated in theoretical and model based analysis below.In order to compare the protocols, the following set of parameters is usually defined:

N=number of nodes.

L=average path length (in hops).

R=average number of active routes per node.

μ=average number of link breakage per second (reflect mobility degree).

α=route activity, which gives how the frequently the node is

changing its destination.

ρ=route concentration factor that monitors the traffic hotspots in MANET.

Proactive, reactive and hybrid protocols have been evaluated theoretically in [19]. It has been found that asymptotic overhead for proactive is $O(N_{1.5})$ due to the process of maintaining and forwarding tables to keep periodic updates. In reactive protocols, route requests and reply messages create overhead of cost $O(N_2)$, while in hybrid protocols this is $O(N_{1.66})$. The number of packets that are produced by proactive protocols per second is $\mu*L*N_2$ while for reactive protocols is $(\alpha+\rho*R*\mu)*L*N_2$. Reactive is found to be better than proactive if $\mu*L*N_2 > (\alpha+\rho*R*\mu)*L*N_2$. It has been concluded proactive protocols can be used mostly in static or quasistatic networks, reactive protocols are preferred in more dynamic networking, while hybrid protocols are more efficient in adapting to changes in network conditions.

Analytical model that compared control overhead with mobility and data traffic for proactive and reactive protocols for MANETs has been also presented in [12]. It has been found that number of packets produced by optimized reactive protocols in MANET is $o_r \mu a L N_2$ and $o_p \mu A N_p N_2$ for optimized proactive protocols, where

o_r= route request optimization factor.

AN_p=active next hops ratio.

a= number of active routes per node (activity).

o_p= broadcast optimization factor.

As a result of comparing those two approaches with existing simulations, it has been observed that OLSR is more scalable than DSR. Moreover, rough high mobility asymptotic for both classes have been compared. It has been found that reactive protocols are better than proactive in high mobility if reactive protocols use routes that do not share links.

Hierarchal routing protocols, geographic position information assisted routing protocols, and hybrid routing protocols are more adaptable to various node destination than flat protocols [17, 18]. In [17], hierarchal routing protocols have been found to be more scalable than flat protocols because they limit the propagation area by structuring the network nodes. However, overheads are increasing with those routing schemes due to location management. Therefore, hierarchal protocols are suitable in scenario like high density but low mobility. Geographic routing protocols also perform well in high density because of the simplicity of location management localized route discovery.

B. *Simulation Observations*

MANET routing protocols are commonly evaluated according to performance metrics such as: delay, delivery ratio, and overheads. Delay is the delay of data processing and queuing in intermediate nodes. Delay increases usually as mobility increases in all different classes of routing protocols. The delivery ratio is the ratio of the number of received packets at the destination to the number of packets that are sent by the source node. This ratio usually decreases as mobility increases. The last metric is the overhead consuming the network bandwidth, which is often high as nodes increase their speed. Adaptable protocol to particular scenario of density and mobility has lower delay and overhead and higher delivery ratio. Several simulations have been carried out to compare different protocols from different classes in different scenarios of nodes mobility and density [6, 11, 19-22].

The results of these simulations indicated that proactive protocols have higher overhead than reactive and hybrid protocols in terms of mobility and density while they have smaller delay than reactive ones. On the other hand, reactive protocols have lower delay than hybrid protocols. Although it is noticed that as the density increases and the mobility decreases, the delivery ratio increases. Proactive protocols have better delivery ratio but hybrid protocols have the best delivery ratio. Hence, they perform better in high density networks.

In [22], several simulations of four protocols have been carried out using GloMoSim simulator. These protocols were distance vector (DV), DSR and AODV as reactive protocols, and WRP as proactive protocol. The simulations have been run under different network conditions like different mobility degrees and different nodes density. It has been found that DSR has highest delay, while WRP has the lowest overhead as mobility increases.

To conclude what we have outlined theoretically and from existing simulations, proactive protocols class perform well in network with low mobility nodes. However, this class can adapt different node density, because they include hierarchal and geographical routing protocols. Moreover, hierarchal, geographic and, and hybrid routing protocols, have been more flexible with high density networks. Therefore, they can operate with medium and high density. In medium density and mobility, reactive protocols can work well.

III. Simulation Model

In this section we present simulations that have been carried out to compare the performances of different protocols from different classes in heterogeneous and homogenous MANET.In homogenous MANETs, all nodes have same capabilities and resources while with heterogeneous MANET different nodes have different resources like transmission range and power saving. We preformed the simulations using the Qualnet emulator.

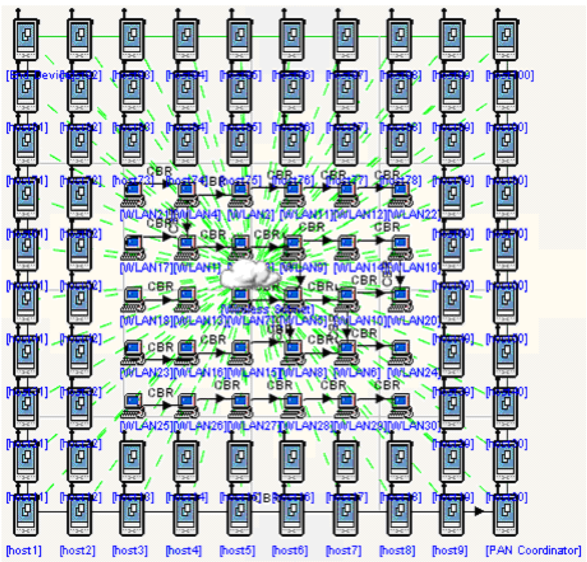

Fig.2.Heterogeneous network with Interference

Fig. 2 illustrates a scenario for the coexistence of 802.15.4 and 802.11b, where 802.15.4 nodes form a multi-hop network and a part of the network is being interfered by 802.11b system. Since the nodes are connected in multi-hop mesh network, packets are routed by visiting the nodes on the routing path. Random way point was used as mobility model with ten different values of speed that were 2, 4,6,8,10,12,14,16,18 and 20 meter/sec. Constant Bit Rate (CBR) was used to generate data traffic. Each packet was 127 bytes for IEEE 802.15.4 nodes, 512 bytes for IEEE 802.11b nodes and transmitted at 1 s interval.

IEEE 802.11b was used as MAC protocol with constant transmission bandwidth of 2Mbps. The transmission power was 15dbm for all IEEE 802.11b nodes and 3dbm for all IEEE 802.15.4 nodes. The simulations run five different protocols that were AODV, DSR, LANMAR, LAR1 and FSR. Data received with errors, Throughput, Average End-to-End Delay, Average jitter, Success rate, control overhead and hop counts were used as performance metrics of each protocol.

IV. Results

In this section, we present the results of simulating AODV, DSR, LANMAR, LAR1 and FSR, with and without different mobility speed of nodes within heterogeneous and homogenous networks.

Fig 3.(a-g) shows the simulation results of heterogeneous network for different routing protocols for different interference size with out assuming the mobility model. For AODV the data received with errors increases linearly when interference size increases. The other protocols are moderately maintaining the data received with errors constant. Throughput and average jitter is decreased to zero when the interference size increases above 40%.Control overhead is more for FSR when compared to LANMAR.Sucess Rate is decreased to zero when the interference size increases above 40% for AODV while DSR maintains success rate as 100% even though the interference size increases.Hopcount for DSR increases linearly when interference size increases. End-End delay is more for LANMAR.It is decreased to zero when the interference size increases above 40%.

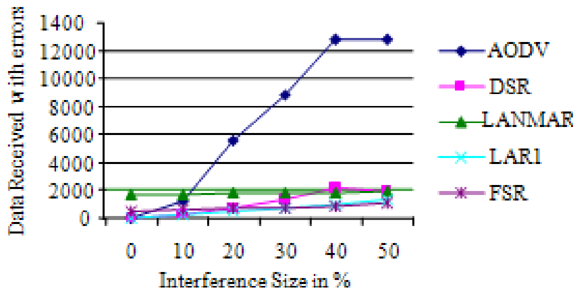

Fig.3.a.Data Received with Errors for IEEE 802.15.4

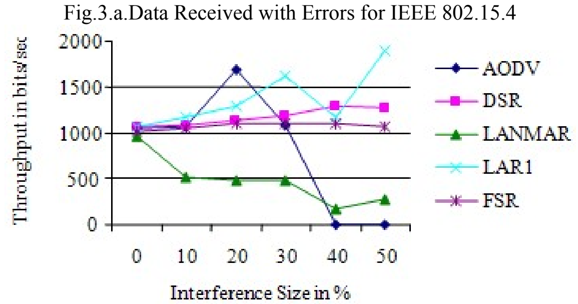

Fig.3.b.Throughput of IEEE 802.15.4

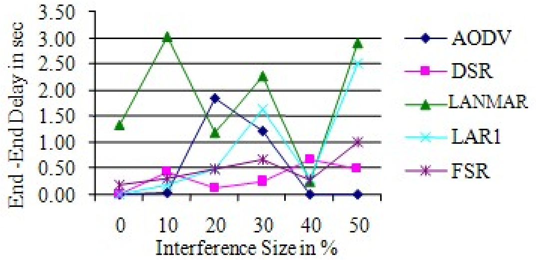

Fig.3.c.End-End delay of IEEE 802.15.4

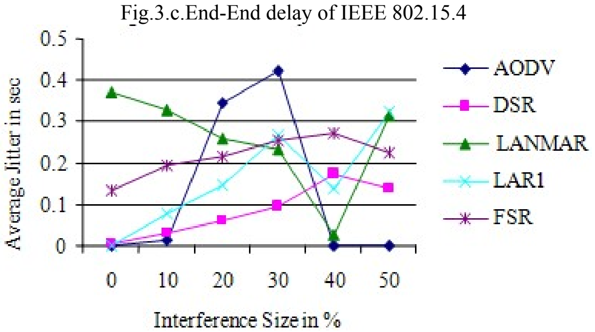

Fig.3.d.Average Jitter of IEEE 802.15.4

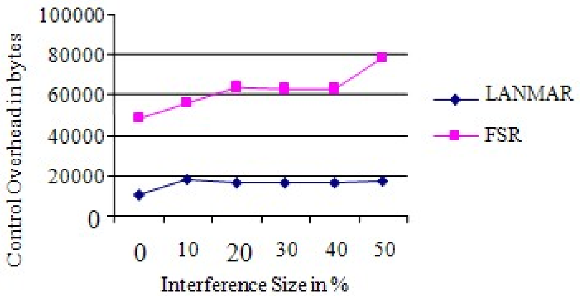

Fig.3.e.Control overhead of IEEE 802.15.4

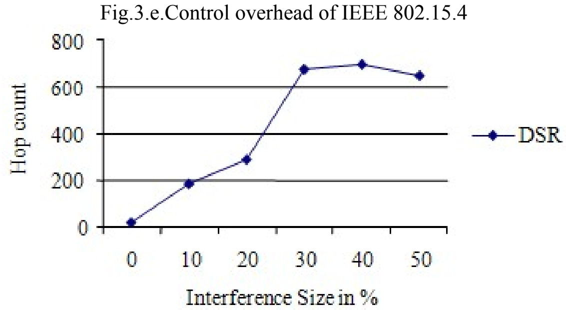

Fig.3.f.Sucess Rate of IEEE 802.15.4

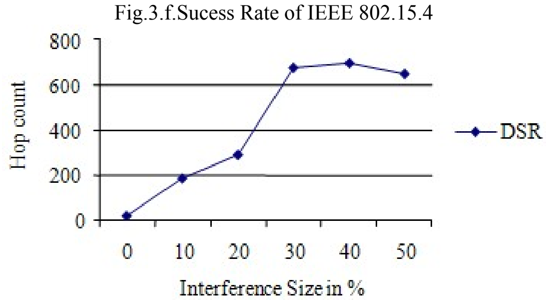

Fig.3.g.Hopcount of IEEE 802.15.4

The following figure (4-9) shows the performance metrics of IEEE 802.15.4 for interference sizes 0, 10,20,30,40 and 50 respectively. The mobility model Random way point is assumed for the performance analysis of heterogeneous networks with the speed of 2, 4,6,8,10,12,14,16,18 and 20 meter/sec. The fig. 4(a-g) shows the simulation results of IEEE 802.15.4 for zero percentage interference (homogeneous) networks.

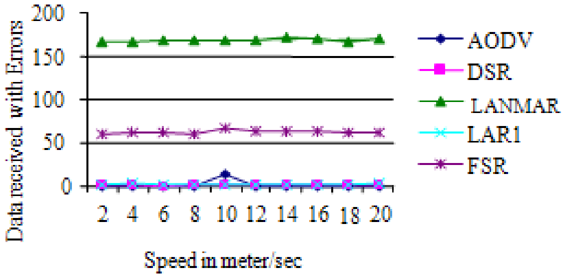

Fig.4.a.Data Received with Errors

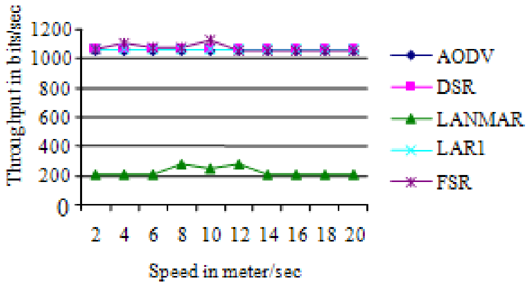

Fig.4.b.Throughput

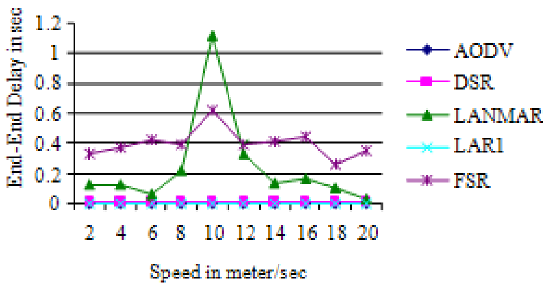

Fig.4.c.End-End delay

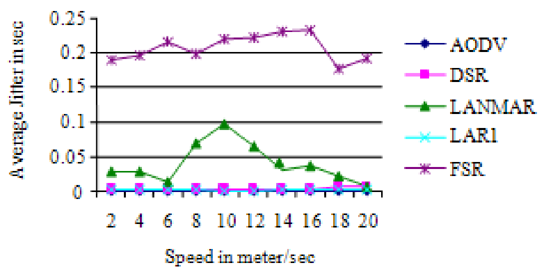

Fig.4.d.Average Jitter

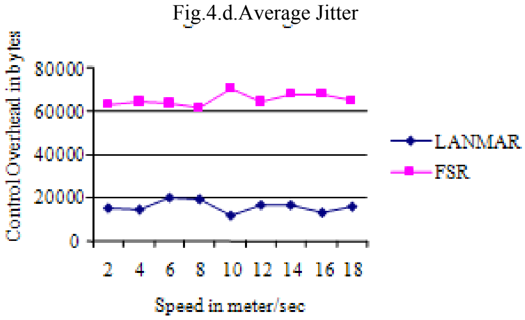

Fig.4.e.Control overhead

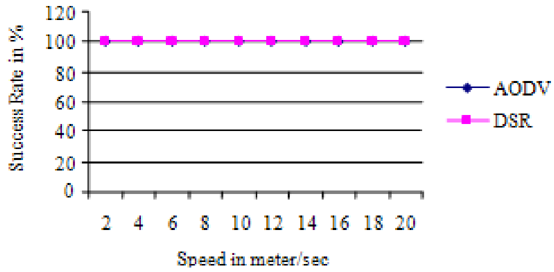

Fig.4.f.Sucess Rate

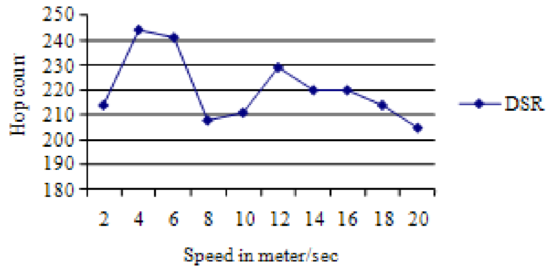

Fig.4.g.Hopcount

For zero percentage interference (homogeneous) networks all protocol behaves constantly through out the speed range. The protocol LANMAR is giving poor results when compared to other protocols.

The fig.5(a-g) shows the simulation results of IEEE 802.15.4 for ten percentage interference networks.

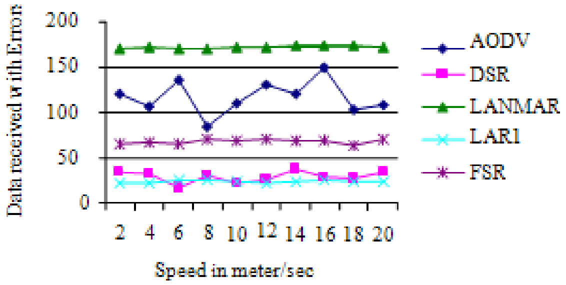

Fig.5.a.Data Received with Errors

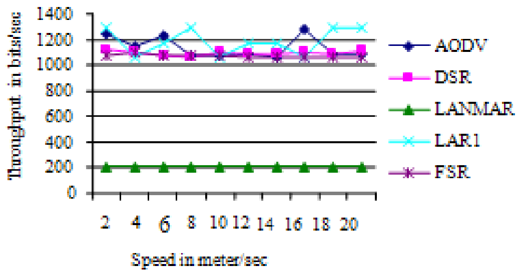

Fig.5.b.Throughput

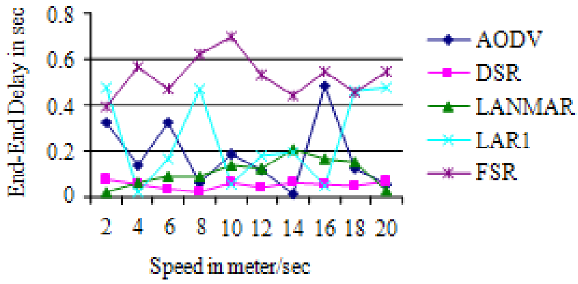

Fig.5.c.End-End delay

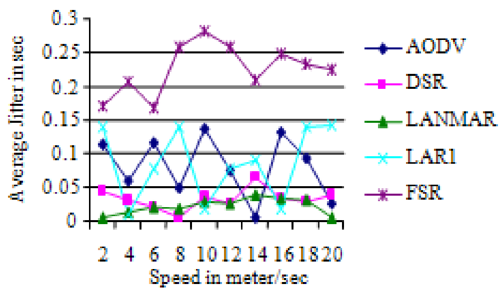

Fig.5.d.Average Jitter

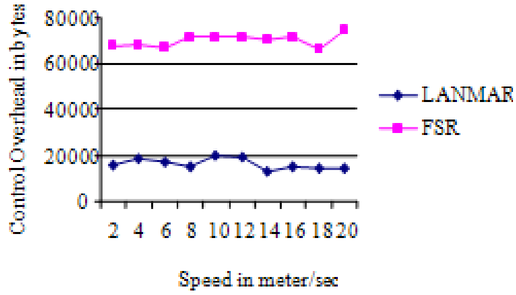

Fig.5.e.Controloverhead

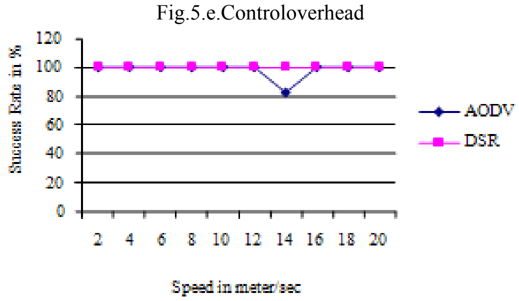

Fig.5.f.Sucess Rate

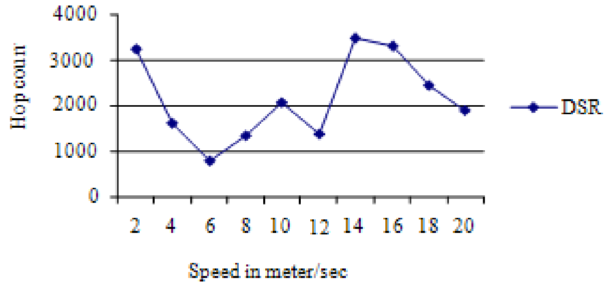

Fig.5.g.Hopcount

The fig.6(a-g) shows the simulation results of IEEE 802.15.4 for twenty percentage interference networks. Packet loss percentage in heterogeneous networking with reactive protocols is between 20 and 25 while it ranges from 60 to 70 for proactive protocols. Overhead is higher too with heterogeneous networking. Proactive protocols as expected have the highest overhead in both homogenous and heterogeneous networking. This is because of periodical updating of routing information.

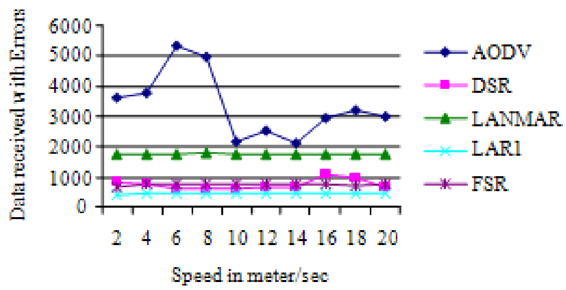

Fig..6a.Data Received with Errors

Fig.6.b.Throughput

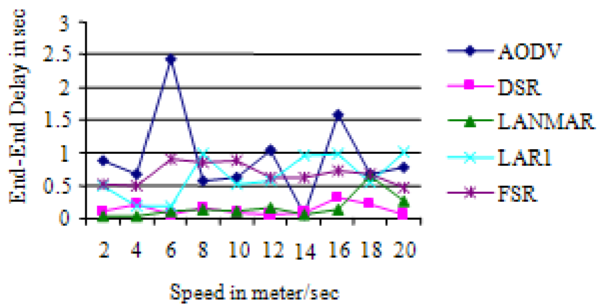

Fig.6.c.End-End delay

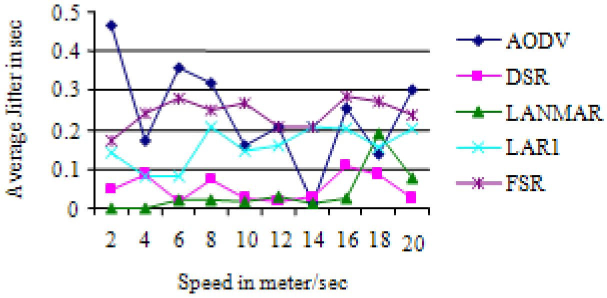

Fig.6.d.Average Jitter

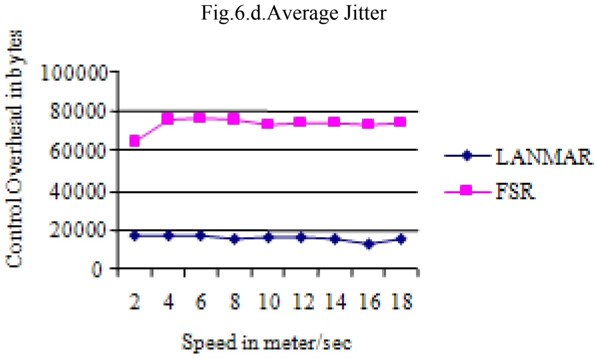

Fig.6.e.Controloverhead

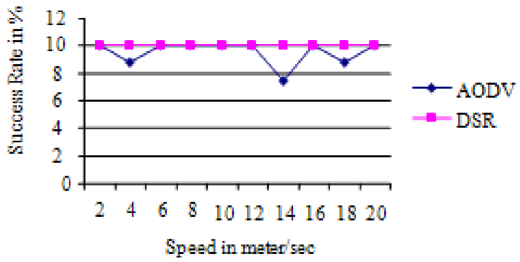

Fig.6.f.Sucess Rate

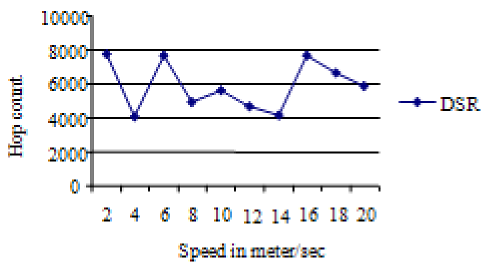

Fig.6.g.Hopcount

The figure 7(a-g) shows the simulation results of IEEE 802.15.4 for thirty percentage interference networks.

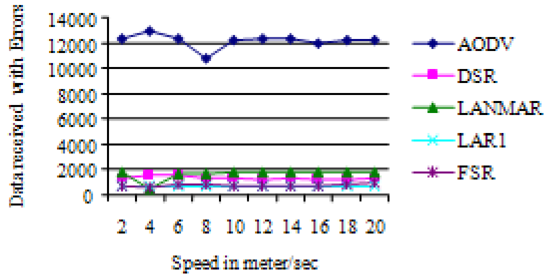

Fig.7.a.Data Received with Errors

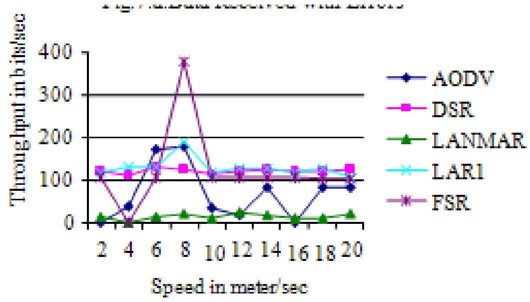

Fig.7.b.Throughput

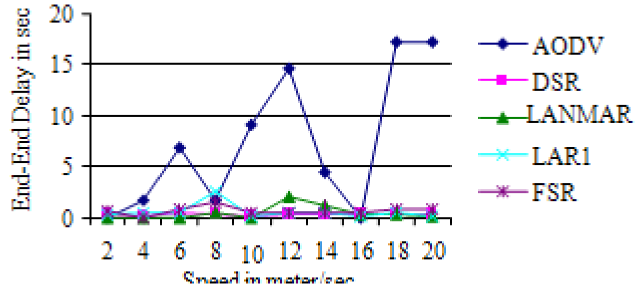

Fig.7.c.End-End delay

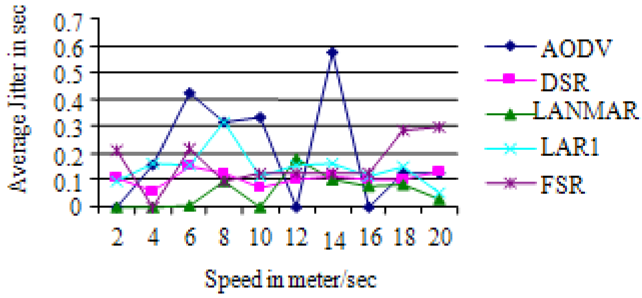

Fig.7.d.Average Jitter

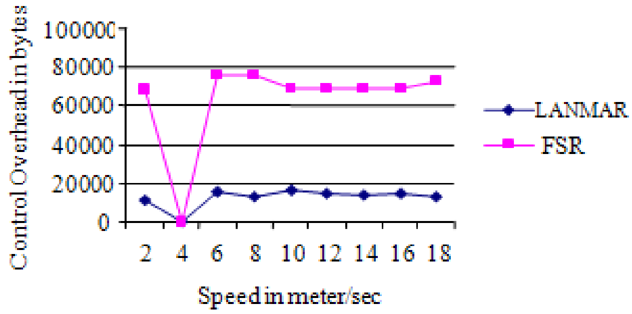

Fig.7.e.Controloverhead

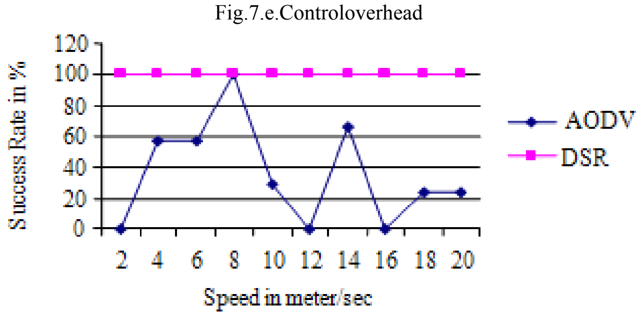

Fig.7.f.Sucess Rate

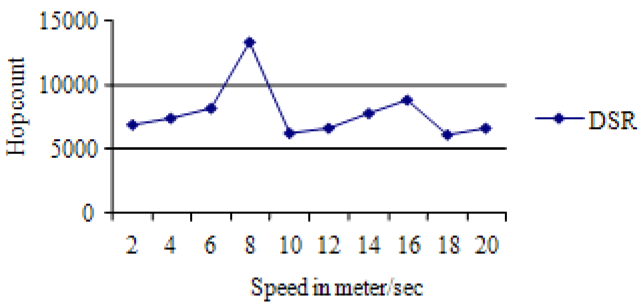

Fig.7.g.Hopcount

The fig. 8(a-g) shows the simulation results of IEEE 802.15.4 for forty percentage interference networks.

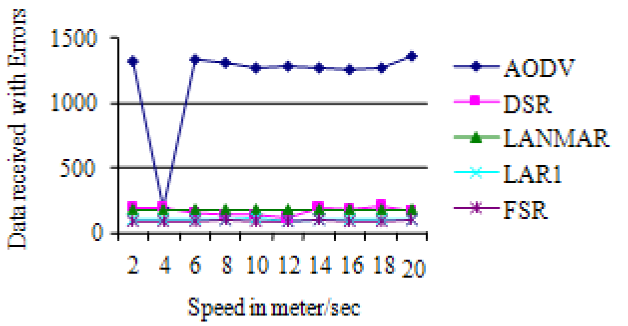

Fig.8.a.Data Received with Errors

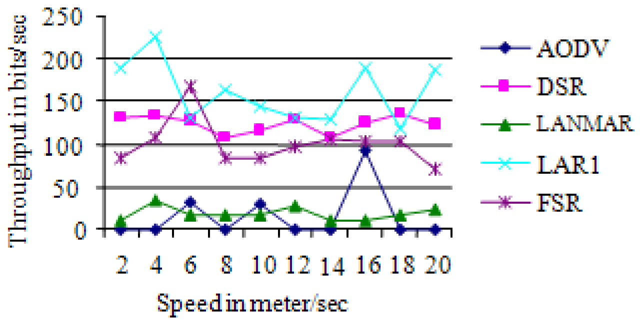

Fig.8.b.Throughput

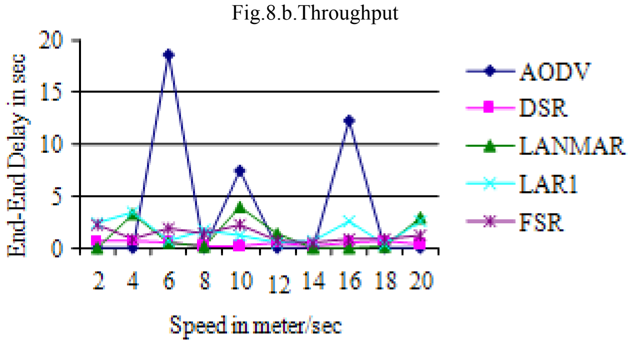

Fig.8.c.End-End delay

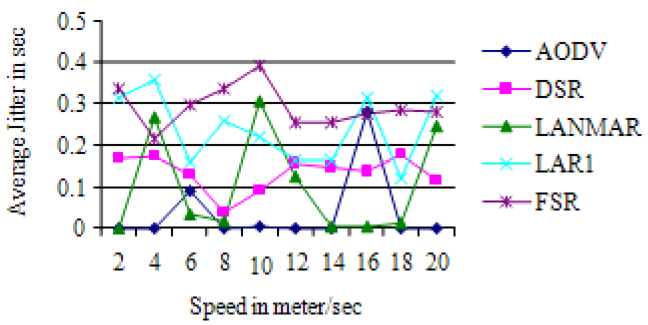

Fig.8.d.Average Jitter

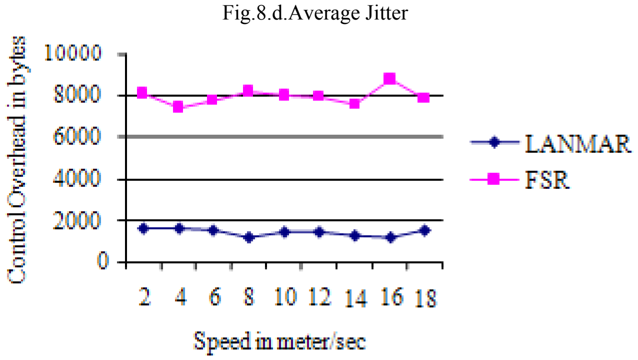

Fig.8.e.Controloverhead

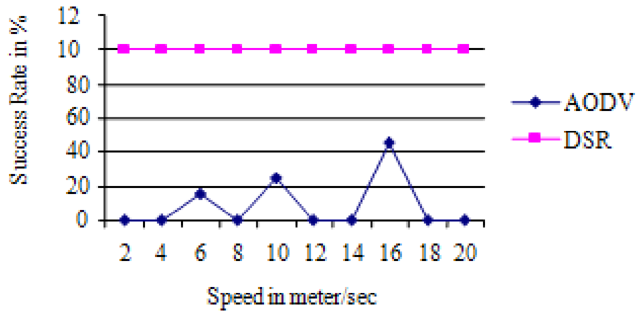

Fig.8.f.Sucess Rate

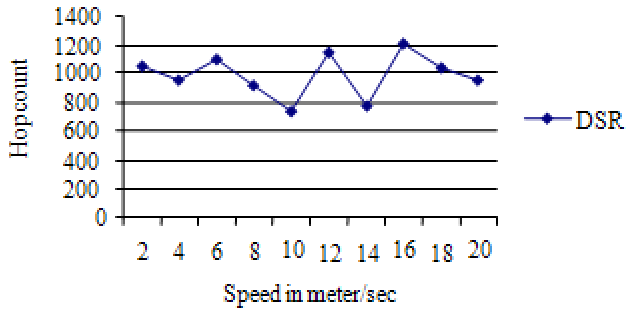

Fig.8.g.Hopcount

The fig. 9(a-g) shows the simulation results of IEEE 802.15.4 for fifty percentage interference networks.

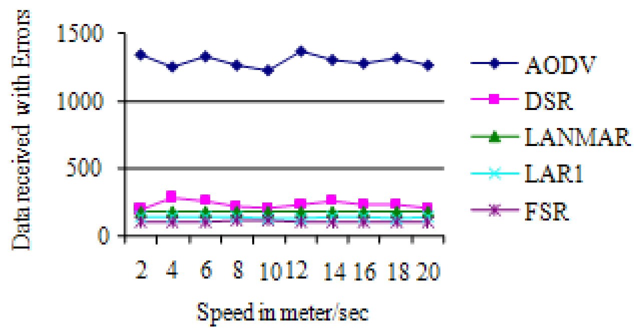

Fig.9.a.Data Received with Errors

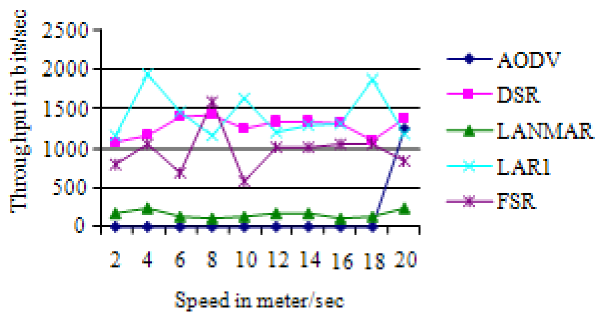

Fig.9.b.Throughput

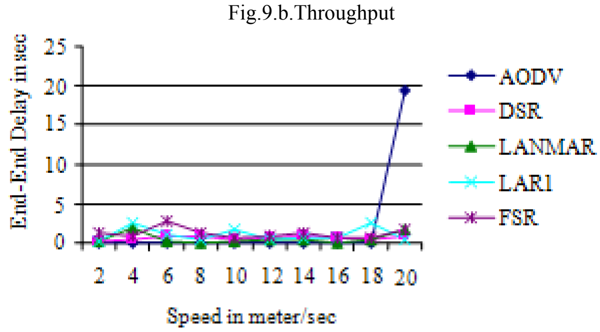

Fig.9.c.End-End delay

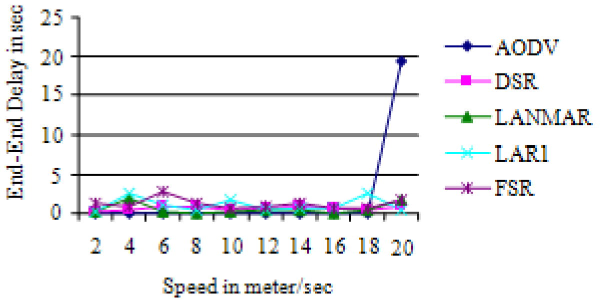

Fig.9.d.Average Jitter

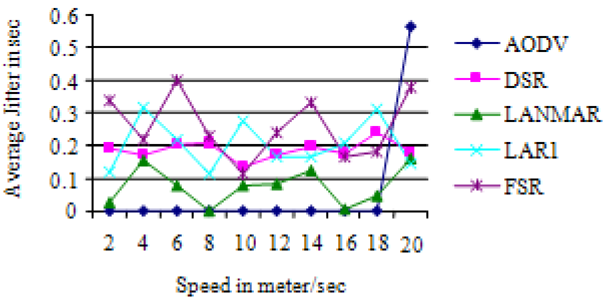

Fig.9.e.Controloverhead

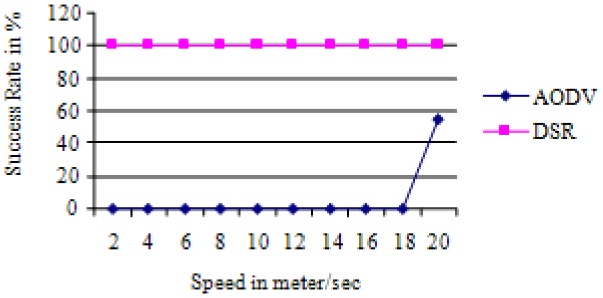

Fig.9.f.Sucess Rate

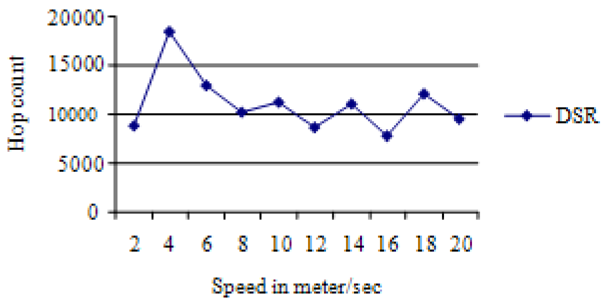

Fig.9.g.Hopcount

Generally, most protocols behave inefficiently and unexpectedly in heterogeneous networks. One of the problems that cause misbehaving is unidirectional link. Some protocols support only bidirectional link between two similar nodes. however, AODV assumes all links between two nodes are bidirectional which gives incorrect routing information. Therefore, this incorrect information creates large delay and packet loss in heterogeneous networking.

However, in heterogeneous networking, there are nodes which have high transmission range to connect to large number of nodes. Therefore, the number of neighbor nodes increases. Hence, as network size increases, powerful nodes will consume more memory and bandwidth in storing neighbor tables and updating routing information. Therefore, proactive protocols might experience higher percentage of packet losing and lower success rate.

V. Conclusion

In Heterogeneous network, mobility, traffic and node density are main network conditions that significantly affect the performance of the network. This issue has been reviewed in this paper. In addition, most of current routing protocols assume homogeneous network conditions where all nodes have the same capabilities and resources. Although homogenous networks are easy to model and analysis, they exhibits poor scalability compared to heterogeneous networks, which consist of different nodes with different resources. In this paper, different simulations have been carried out to compare the performance of different routing protocols in homogenous and heterogeneous networks. All simulated protocols misbehave in heterogeneous networks. They also suffer from high delays and achieve very low success rate. This shows that the current routing protocols for MANET are inadaptable for heterogeneous networking.

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