CHAPTER 7

SUMMARY AND CONCLUSIONS

The ad-hoc network is an infrastructure-less, self-configuring, self-motivated, arbitrary, rapidly changing, and multi-hop network that is composed of bandwidth constrained wireless links without an aid of the centrally controlled routers or servers. Due to these properties, it has got potential applications in various fields such as tactical environments, emergency operations, home and enterprise, commercial, civilian environments, location-aware services, and extension of coverage etc.

The term “Ad-Hoc Network” was adopted first time in the 95’s conference session of the Internet Engineering Task Force (IETF) by the IEEE 802.11 subcommittee. Initially, ad-hoc network was only known in the military realms (i.e. the first and second generations of ad-hoc networks). And, its name was the Packet Radio Network, which had been supported by the Defense Advanced Research Projects Agency (DARPA). At that time, its name had been given as packet radio network because this network could provide connectivity among numbers of wireless users on combat zone. Later on (i.e. in the third generation, after 90’s), its applications has been founded in the non-military zones also and afterwards, it has become a vibrant area of research among the researchers. Moreover, recently (near about 97’s and 98’s), newer techniques like Bluetooth, Wi-Fi, and HiperLan2 have been introduced, and the deployment of ad-hoc network concept has significantly made possible to the outside of the military realm. As a result, the applications of the ad-hoc network have been seen in many fields as mentioned in the table (1.1). The possible applications of the ad-hoc network in many fields as well as its contemporary relevance and future promise in the next generation of wireless communications, which has indeed motivated the thesis's author to select this area as his research work.

An ad-hoc network is vulnerable due to its fundamental characteristics such as open medium, dynamic topology, distributed operation, autonomous terminal, lightweight terminals, asymmetrical communication, fluctuating link capacity and constrained capability etc. Hence, stable routing is one of the challenging tasks in this network. However, routing in the ad-hoc network is highly complex because of node mobility, limited transmission range of nodes due to its power constraints and security issues etc. Therefore, the author has been motivated to analyze and observe the performance of routing protocol (especially AODV) in the wide range of scenarios.

The AODV routing protocol is a simple, efficient, effective, and novel approach for the operation in the ad-hoc network environment, which mainly comes under the reactive/on-demand routing. However, AODV falls under the on-demand routing protocol, but it still uses characteristics of a proactive routing protocol. It takes the advantages of the DSR and DSDV algorithm; in the sense that it uses the concept of route discovery & route maintenance from DSR, and the idea of sequence numbers & sending of periodic Hello messages from DSDV. AODV offers the self-starting, multi-hop and dynamic routing among the participating users, who wish to deploy and maintain the ad-hoc network. This routing protocol allows mobile users to adopt the routes quickly for the new destinations. Moreover, it also gives permission to mobile users to act fast in the case of link breakages and changes in the network topology promptly. The AODV routing algorithm is actually motivated due to its limited bandwidth that is available in the media and used for communications, especially in the wireless medium. The idea of getting routes purely on-demand makes AODV routing a very useful and preferred algorithm for the ad-hoc network.

In this routing due to the on-demand nature of AODV protocols, the route maintenance parameters are one of the key concepts for the route discovery and route maintenance process, which basically deals with the topology changes and provides a stable path in the network. Moreover, some available studies concerning to the ad-hoc networks have been reviewed in the SOTA section (1.4.6). From there one can easily observe that the thesis research work marks a shift from the previous research work in which it considers the various route maintenance parameters for the study. Therefore, the main variables of this thesis are the number of route maintenance parameters (ART & DPC) and various determining factors (mobility, transmission range, NLD and ANs/SD pairs) that may significantly affect the AODV network stability.

The prime purpose of the present thesis is to provide more stable routing in AODV network. In order to provide more stable routing in AODV network, it is absolutely essential to take into consideration the timeout value for cached routes and timeout value after which the expired cached routes are completely deleted from the routing table. These two timeout values are called as ART and Delete Period (DP) respectively, and they minimize the route failure issues by providing alternative routes for the data packets. In this thesis, ART and DPC (where DPC denotes the multiple for DP, i.e. "DP = *DPC × Max {ART or Hello_Interval}*") are termed as route maintenance parameters and are being used to improve the performance of the AODV routing. Actually, in AODV routing, it is suggested (by C.E. Perkins) that the value of ART and DPC should be a constant. In other words, their value is generalized for all kinds of applications or traffic generators. However, it has been observed from the thesis work that the choice of their values according to network behavior and traffic generators may significantly increase the network performance or provide the stable routing in the network. In order to observe and analyze the AODV routing performance under the wide range of created scenarios and situations, the present thesis is organized into following seven chapters.

In chapter 1, the theme of the current research work is reported in detail. Here, the historical development of the wireless technology and the ad-hoc network has been presented in a chronological manner. Moreover, this chapter also gives an overview of the different kinds of wireless networks that are currently available in the market. Further, it also explains the fundamental concepts of the ad-hoc network with its possible present and future applications along with its major salient features. Later on, the various key issues (like routing protocols, mobility model, medium access control, QoS and simulation software) related to this network are outlined in the background and SOTA section. At the end of SOTA section, some available studies related to ad-hoc networks are reviewed, and the close analysis of the detailed literature review established the research gaps. Finally, chapter 1 comes up with author's motivation, objectives of the present thesis, and organization of all chapters.

In chapter 2, the concept of AODV routing protocol, various route maintenance parameters, and different determining factors are deeply discussed. At first, this chapter explains the different packet format of AODV that are RREQ, RREP & RERR. Later on, routing operation of AODV are clearly presented in depth, in which it covers the pictorial presentation of the AODV routing procedure, route discovery process (like reverse & forward route setup, and the step-by-step procedure for route discovery), route maintenance process, and management of routing table & local connectivity. Further, it also indicates the advantages and disadvantages of the AODV routing protocol. After that, chapter 2 also lists the various route maintenance/configuration parameters with their proper explanation, and clearly describes the concept of active route timeout & delete period constant. At the end of this chapter, the various determining factors (like mobility, transmission range, NLD, and ANs/SD pair) are talking about. And, also discusses about how these various determining factors are affecting the AODV performance.

In chapter 3, the AODV routing protocol's performance is analyzed by variation in the route maintenance parameters from their default value by using two different simulation tools that are NS-3 & QualNet. Moreover, in this case, the CBR traffic generator is provided among the mobile nodes. As, in most of the reported work, the ad-hoc networks were simulated as a function of mobility of nodes, number of nodes, size of networks, and transmission range of nodes but not as a function of the route maintenance parameters; such as ART & DPC. Therefore, this chapter is showing its interest to analyze how the performance of the AODV routing protocol is influenced when the ART & DPC are varied from their default value. In chapter 3, two different simulation studies have been conducted under different simulation tools. The first one is by using NS-3 and the second one uses QualNet.

In the first simulation study, the AODV routing performance has been observed for a constant scenario by using NS-3. Here, it is tested under the random waypoint topology for a fixed number of nodes, fixed CBR SD pair, and is subjected to the IEEE 802.11 MAC protocol. In this case, the effect of variations of ART & DPC on the net throughput & PDR has been analyzed graphically. Here, the analysis is initiated with a narrow range of ART (2, 3, 4) & DPC (4, 5, 6) and found that for ART=3 & 4, the net throughput and PDR decreases monotonously. However, for ART=2 seconds, it has local minima. Therefore, the analysis is extended into the region around ART=2 to observe this deep phenomenon very carefully. Now, the ART values are extended too far away from its default value in order to observe the effect of abrupt changing of ART on the network. Analysis has also been done for the different values of DPC just to observe network behavior as we go far from the default value of DPC. Hence, from this analysis, it is clear that if there is a change in the parameters far away from their default value, the performance becomes abrupt. Furthermore, even if one parameter is kept constant and another parameter is varied quite away from the default value, the network acted oppositely at the default value. However, if the result is taken for network performance only on net throughput or PDR, the maximum performance of AODV is found for ‘ART’ & ‘DPC’ combination of 2.5 & 5.0, respectively. Although the AODV protocol suggested that the original ART default value is 3 seconds. However, in this scenario, the best performance is observed at ART=2.5 seconds. Therefore, it is clear that as per this analysis ART value is 0.5 second less than the original default value, which results in less memory overheads. In other words, especially, in this type of scenario to get more stable routing, ART value should be less than its default value.

In the second simulation study, the performance of the AODV routing protocol has been tested under random waypoint topology for a constant scenario, but for different SD pairs and by using the QualNet simulation tool. Again, AODV routing performance is subjected to IEEE 802.11 MAC protocol for a fixed number of nodes. Here, ART & DPC variations impact is analyzed in a graphical manner on different QoS metrics such as throughput, average end-to-end delay, average jitter, and percentage of loss packet. In this simulation scenario, various chosen ART value is 0.5, 2.0, 3.0, 3.5, & 5.0 and for each ART value, the value of DPC has been varied from 2 to 8 in a regular unit interval. In this section, two simulation experiments are conducted for two different SD pairs (5 & 7), where network density is kept constant, and its value is 20. The impact of these variations phenomena of ART & DPC has deeply and closely been analyzed on AODV routing, which is tabulated in the table (3.6). From there, it is clear that if the parameter value is changed far away from its default value, then the network shows an unexpected behavior. Even if one parameter is kept constant and the other is varied quite away from its default value, the network exhibits odd behavior than its normal one. One may also observe from the table (3.6), ART=3 acquires the best performance for all QoS metrics except in the case of delay for 5 SD pair, here, it is noticed at ART=3.5 seconds. Whereas, the best one is found at different DPC value. For all QoS metrics, DPC value is less than its original default value excluding jitter, which results in less memory overheads. Moreover, it could also be seen that 7 SD pair has outperformed except jitter. In the case of jitter, 5 SD pair delivers better results, this might be feasible because of lesser traffic in the network. And hence, route breakage is less, particularly. Therefore, the performance is better. From the above analysis, this section finally concludes that the network performance is constrained of QoS metrics. Moreover, the selection of the default values of ART & DPC may depend on the user's QoS requirement.

In chapter 4, the performance of the AODV routing protocol has been analyzed and compared to two different traffic generators: Constant Bit Rate (CBR) and Variable Bit Rate (VBR). Again, in this chapter the comparative simulation study between CBR & VBR has been done under the influence of route maintenance parameters. From the reported literature review, it is clear that several researchers have carried out comparative studies between various routing protocols. However, they were limited to CBR & TCP traffic models, and very few included the route maintenance parameters but only for CBR traffic. Therefore, this chapter presents the comparative study between CBR & VBR traffic under the influence of route maintenance parameters like ART & DPC. This section also makes an effort to point out an optimal relation between the route maintenance parameters and both traffic generators in which AODV network provides stable routing. Since in real time applications, most of the time, traffic is variable. Hence, it is absolutely necessary and exciting to carry out this comparative study between CBR & VBR in order to observe the performance differences. Here, AODV performance evaluation and comparison are based on throughput, average end-to-end delay, & average jitter, and again QualNet simulation tool is used to carry out the results.

Chapter 4 mainly conducts two different simulation studies in order to analyze and compare the AODV network performance for both traffic generators: one is for variable ART at fixed ‘NLD & SD pair’ and the second one is for variable SD pair at fixed ‘NLD & ART’. The first simulation study mainly determines how AODV behavior gets changed in the varying ART environment under CBR & VBR traffic generators, which are reported in section (4.4.1). The first study concludes that the curve ART=1 at DPC=6 gives the best performance in terms of QoS metrics for VBR traffic, whereas in the case of CBR traffic best performance is observed by the curve ART=3 at DPC=3. Therefore, it can be said that whenever traffic is variable, there is no need to hold route state information for a longer time because it creates more memory overheads. While for constant traffic, the value of ART is suggested at near about its default value. In CBR traffic, for ART<3, the worst performance is noticed because of the new route discovery process while a valid route is still there. In addition, again for ART>3, the poor performance is experienced in the network due to the packets sent to an invalid route. Hence, initiation of the RERR message instead of a new route discovery process takes place. Moreover, this chapter also concludes that almost for all QoS metrics, the overall CBR performance is better than VBR. The reason of VBR poor performance is may possibly due to the variable nature of traffic where each time synchronization is needed between the particular source and destination nodes. The second simulation study of this chapter has been discussed in depth in section (4.4.2). This section concludes that the network performance increases with an increase in the SD pair in terms of throughput and average end-to-end delay for both traffic generators. It may be due to an increase in generating the data packets from the client, and the route discovery process becomes easier with an increase in SD pair, respectively. However, it is expected that after a particular increase in the SD pair (like more than 50 % of total NLD), the performance will start to decrease because of a large number of control overhead packets in the network. Whereas in the case of jitter, the performance decreases with an increase in the SD pair because it leads frequent link breakage in the network. Moreover, this section also concludes that the overall CBR has outperformed than VBR almost for all SD pairs. It might be possible because this simulation study has been conducted at the default value of ART, and CBR traffic performs better at near the default ART value. Moreover, the requirement of synchronization may also be a reason for the poor performance of VBR traffic.

From the above discussion, chapter 4 concludes that the selection of default value of ART & DPC also depends on traffic generators (i.e. their default values are application dependent). Moreover, of course, the selection of their proper default values according to the applications may greatly increase the network performance (i.e. may provide the stable routing in the network). Furthermore, the selection of default value according to traffic generators could also reduce the memory overheads.

In chapter 5, reported research work tries to analyze an optimal relation between the route maintenance parameters and the various determining factors (like NLD, mobility & transmission range) in which network provides a stable behavior (i.e. offers the best performance) while focusing on the AODV routing especially. As, in most of the research work that presented in SOTA section (1.4.6), several researchers have attempted to observe the AODV routing performance by considering various factors like size of network, number of nodes in the given area, transmission range, mobility etc. However, they were restricted to only these factors and a few of them separately considered the route maintenance parameters only, but the combine research work between the route maintenance parameters and determining factors has not been carried out yet. Therefore, in this part of thesis work, an attempt is also made to analyze how AODV routing performance is influenced, when various determining factors are taken into account along with the route maintenance parameters. Here, routing performance is again subjected to IEEE 802.11 MAC protocol under random waypoint topology, but for the different NLD and a fixed number of SD pair. In this case, provided traffic generator between the mobile nodes is CBR. Furthermore, research work of this chapter uses QualNet simulation tool to carry out the results. Here, the performance observation is based on throughput, delay, and jitter metrics.

In order to analyze the best relation between the various determining factors and route maintenance parameters, this chapter creates two different scenarios, and each scenario presents two separate cases.

The case-1 of scenario-1 analyzes the impact of variations of ART on different QoS metrics for various values of node's mobility (like 0.5, 5, 10, & 15 (in mps)). Here, ART value is varied as 0.5, 1, 3, 5, 7, 9, & 11 (in sec). This section concludes that at higher node's mobility such as 5, 10, & 15, the performance in terms of QoS metrics is not good with an increase in ART value. It may be due to the frequent topology changes that are more common at higher node's mobility. Hence, it is suggested that the route state information should not be kept for a longer time in a highly mobile environment (i.e. AODV network performs best at lower ART value (ART<1), especially in the case of higher node's mobility). If mobility <0.5 mps, the performance becomes good and it is nearly constant for other higher ART values. This result is obvious because the node's mobility is almost stationary and hence, changes in ART value do not affect the network performance. Here, the best throughput is observed at ART=1 whereas for delay & jitter, the best one is at ART=0.5 (i.e. better QoS metrics at ART<3 for all node's mobility). Moreover, the 2nd case of scenario-1 concludes that the overall throughput increases as the NLD increase (70 to 90). It may be due to the increase in intermediate nodes, hence connectivity also increases in the network as NLD increases. However, after a certain increase in NLD value, throughput starts decreasing because the area is constant and there could be congestion in the network. Case-2 also concludes that for all values of NLD at lower node's mobility, the throughput values are high as compared to higher node's mobility. Further, it may also observe that at ART=3 for all NLD, the performance regarding throughput is decreased because of the slow reaction to the rapid changes in the network topology, particularly at higher node's mobility. Moreover, at ART=1 instead of its default value, it has a significant throughput outcome, especially, at the higher node's mobility. It may due to easy adaptation by the network to the rapid changes in topology at a lower ART value.

The 2nd scenario of chapter 5 is mainly concerned to analyze the effect of various transmission ranges on the throughput at default QualNet transmission power (15 dbm) and calculated transmission powers which have been calculated by using equation-1. Here, 1st case concludes that the throughput value increases up to 300 meters of the transmission range. It may due to the number of hops reduces as the transmission range increases, which in turn reduces the possibility of route breakage. After that, throughput value is decreased because 15dbm transmission power is not adequate to transmit the packets beyond 300 meters (here, channel bandwidth has been fixed at 11 Mbps). It is also concluded that at ART=1, maximum throughput is acquired almost for all transmission ranges, and it is almost constant for other higher values of ART. It may be due to the constant node's mobility throughout the simulation (here, it is fixed at 5 mps). Hence, changes in ART value do not affect the throughput much. Furthermore, the same scenario is observed for the calculated transmission powers (15.00, 18.57, 21.07, 23.00, 24.59, 25.93, 27.00, 28.10, and 29.03 dbm). Here, it is concluded that the throughput value increases up to 350 meters of transmission range. Later on, it becomes almost constant for higher values of transmission range. The 2nd case of scenario-2 concludes that the throughput value is higher at lower node's mobility for all transmission ranges. Moreover, it is almost constant at high node's mobility that is noticed in higher transmission ranges, particularly. The main reason for this outcome is the reduction in the number of hops towards a particular destination as transmission range increases.

In chapter 6, the comparative performance analysis between the various routing protocols has been carried out under the varying pause time environment. As, in the presented research work in SOTA section, many research studies have already been conducted in order to analyze and to compare the characteristics of various routing protocols through different QoS metrics for various situations and applications. However, these studies have considered the different set of routing protocols for their analysis as chosen in this thesis work. Hence, the prime concern of this thesis chapter is subjected to comparative performance analysis between five routing protocols, out of which four are reactive (AODV, DSR, DYMO, & IERP) in nature and the remaining one is IARP that is proactive in nature. This part of thesis work is mainly showing its attention to see the performance differences between these five routing protocols in the variable pause time environment, where it is varied from 0 to 100 seconds in a regular interval of 20 seconds. Here, the performance observation and comparison are based on performance measuring metrics like throughput, end-to-end delay, jitter, and PDR.

As here, mobile nodes are moving according to random waypoint mobility model. Hence, it is absolutely important to conduct the simulation study in a variable pause time environment in order to observe that how the behavior of routing protocols is getting changed whenever the network topology turns into a relatively stable environment from a highly dynamic one (lower values of pause time signify dynamic environment).

Here, it is concluded that the AODV gives better throughput and PDR performance than the other remaining routing protocols for the range of pause time. The reason behind the best AODV performance may be the lesser number of control overhead packets because of on-demand nature. Hence, the minimum number of packets gets dropped in this case. Also, this chapter concludes that the IERP & IARP gives the worst performance in terms of throughput & PDR. It may be due to the limited proactive and reactive features in IERP & IARP. Moreover, IARP gives the best performance in terms of end-to-end delay and jitter than the other remaining routing protocols, and the performance is almost constant throughout the variation in pause time. The reason may be due to some degree of the nature of proactive maintenance within routing zones, which makes it more and more robust to the changes in the network topology. In addition, also, the route discovery process becomes easier due to this nature. Furthermore, in this case, the route breakage issues are also minimized because of multiple-hop paths concept within the routing zone. After IARP, AODV routing protocol performs satisfactorily in terms of end-to-end delay & jitter, and here performance is also constant throughout the range of pause time. It may be due to the AODV have a mechanism to adopt the topology changes quickly in the network. From the above discussion, overall it is concluded that the AODV performs better than all other remaining routing protocols for throughput and PDR throughout the range of pause time, and second best for the end-to-end delay and jitter.

In chapter 7, the work embodied in the present thesis has been summarized, and the significant conclusions have been drawn from the major findings. Furthermore, this chapter also includes the future prospective of current research work.

7.1 Scope for Further Studies

In the present research work, the performance of the AODV routing protocol is analyzed and compared with the vast range of scenarios for CBR & VBR traffic generators by considering ART & DPC route maintenance parameters and few determining factors like mobility, transmission range, NLD & SD pair. In other words, it can be said that the present research work tries to identify the optimal default value for ART & DPC. In addition, it also attempts to get an optimal relation between the route maintenance parameters and various determining factors in the broad range of scenarios in order to provide stable routing in the AODV network. Moreover, in the second last chapter of the present thesis, the comparative study between the chosen routing protocols has also been carried out in varying pause time environment. It is expected that the present study would be useful for anyone to get stable routing in the AODV network. Moreover, in future, the new routing algorithm can be designed by using performance details obtained through thesis analysis or work can be done for improving the different features of the routing protocol. In this context, the scope of the present thesis for future extension is as follows:

In the present research work, only ART & DPC route maintenance parameters are considered to analyze the AODV network performance. Here, another important route maintenance parameters (like NODE TRAVERSAL TIME, NET DIAMETER, NET TRAVERSAL TIME, PATH DISCOVERY TIME etc.) that are associated with the operations of the AODV routing protocol have not been incorporated, which may provide a more realistic scenario.

Moreover, in current research work, only random waypoint mobility model has been chosen to define the movement pattern of mobile nodes in the network. However, in future, this research work could be extended to the other mobility models (such as random walk, gauss-markov, city section, probabilistic version of random walk etc.) in order to analyze and compare the network performance for the targeted real life applications in a proper way.

In this research work, only CBR & VBR traffic generators are considered for the study. Moreover, other real-time traffic generators (like VoIP, TELNET, FTP etc.) may also be included in the future prospective of current research work in order to reflect the complex nature of traffic in real applications. In future, this research work could also be carried out for the other reactive routing protocols so that an exhaustive comparison of various reactive routing protocols can be made. All reactive routing protocols expected to present the different results.

The author feels that the study carried out in the present thesis would certainly help and motivate the readers and other researchers in the field of ad-hoc networking.