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Effect of NTT on Performance of AODV in a Grid Topology-Based Wireless Ad Hoc Network

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Abstract

Routing in wireless ad hoc networks that enable nodes, acting as routers also, to find the best path between source and destination nodes, taking into account cost, is a very challenging task. In the present work, an investigation of performance of AODV routing protocol in a grid topology based ad hoc network by varying value of node traversal time (NTT) and taking into account absence and presence of Hello messages is reported. A set of metrics, including Average End-to-End Delay, Packet Delivery Ratio, Throughput, Routing Overhead, Route Error Overhead, Normalized Routing Load, Average Hop Count, and Total Number of Received Data Packets, has been used to assess the performance of AODV in the grid network. Performance of AODV routing protocol varies in the value of NTT. Throughput in grid topology, by and large, is observed decrease with an increase in NTT. However, explicit relations between certain metrics with NTT as well as simulation time could not be traced due to intricacies involved in combination of states of various links and flows in the grid topology. To have better insights, grid topologies of two, three, and four rows are planned to be investigated in the future.

Category: Network and Communications

Keywords: Ad hoc networks; AODV; NTT; IEEE 802.11b; NS-3; Grid topology

I. INTRODUCTION

Wireless communication technologies have proliferated over the last few decades. Wireless technologies are increasingly being used to meet the communication needs of large groups of people worldwide, and this trend is expected to continue. To date, more than 8 billion people worldwide are using cellular services and their wireless devices to communicate via voice and data. In most parts of the world, wireless technologies are more common than traditional wireline communications [1]. The popularity of wireless technologies can be attributed to several factors. Wireless communication technologies are mostly implemented using fixed infrastructure to offer a variety of applications.

In recent decades, a new wireless architecture has emerged that does not rely on fixed infrastructure. There are no unique roles for any of the nodes in this architecture. The "ad hoc" mode architecture of 802.11 is one example of this architecture, as shown in Fig. 1. In this architecture, 802.11 nodes communicate without using access points. Nodes communicate with other nodes via their neighbors. Nodes that are close can discover their neighbors. As soon as a node requires to communicate with another node, it sends the traffic to its

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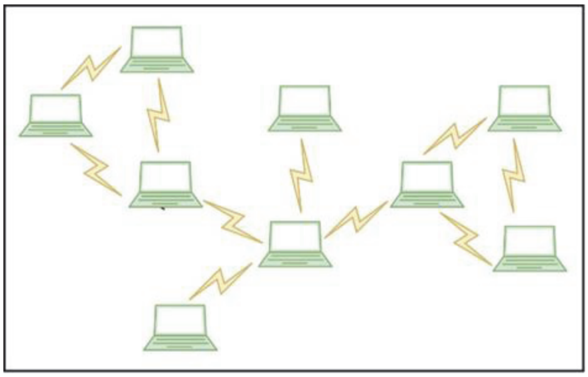


Fig. 1. 802.11 ad hoc mode architecture.

neighbors, which in turn forwards the traffic to their neighbors, and the process is repeated many times over until the traffic reaches its destination point. This architecture necessitates that each node in the network acts as a router by determining the paths packets take to reach their destinations. "Networks that support the ad hoc architecture are typically called wireless ad hoc networks or mobile ad hoc networks (MANET)." Typically, such networks are assumed to be self-healing and self-forming. This is because the typical applications of such networks necessitate nodes forming networks quickly and without human intervention [1].

Routing in such ad hoc networks is complicated because traditional routing protocols do not perform well in intermittent connectivity, frequent movement, and network splits and joints. The overhead generated by such events in typical routing protocols is substantial, and the network requires a significant amount of time to regain stability after some of these events. It has been recognized by the Internet Engineering Task Force (IETF), which is the primary standardization body for the internet, that existing routing protocols are unable to meet the specific requirements of MANETs, and the IETF has played an essential role in the development of novel MANET routing protocols. This is accomplished through the IETF MANET Working Group which has served as a focal point for much-related research. This group was founded in 1997 and has since developed several of the most widely used MANET routing protocols, including the optimized link state routing (OLSR) and ad hoc on-demand distance vector (AODV) protocols [2].

AODV is a reactive routing protocol that C. Perkins and E. Royer developed in 1999 as a routing protocol for ad hoc networks [3]. As mentioned in RFC 3561 [4], the performance of AODV is greatly influenced by the choice of its parameters (net traversal time, hello interval, active route time out, path discovery time, ring traversal time, node traversal time, my route timeout, etc.). Among all these parameters, one of the most critical parameters of the AODV routing protocol is Node Traversal Time (NTT). According to RFC 3561 [4], NODE_TRAVERSAL_TIME is a conservative estimate of the average one-hop traversal time for packets and should include queuing delays, interrupt processing times, and transfer times. NTT is typically set to a fixed value of 40 ms. Regarding traffic load, node mobility, density of nodes, and link conditions in ad hoc wireless networks, this fixed value of NTT does not reflect a complete dynamic topology.

If a node in AODV is a member of the active route, it may broadcast local Hello messages at a predefined 'Hello Interval' to provide connectivity information to other nodes in the route. MAC acknowledgment is another way of detecting the loss of local connectivity of neighbors when using the AODV routing protocol in the absence of Hello messages.

A significant amount of works focused on the investigation of the effect of choice of the value of certain parameters of AODV routing protocol on its performance have been reported [5–14]. My route timeout, node traversal time, path discovery time, ring traversal time, net traversal time, hello interval, active route timeout, and so on are among the parameters of interest. However, there are just a few works in the literature that took into account the effect of variation in NTT on the performance of AODV. Chin et al. [15] reported a testbed-based study in which NTT and network diameter were adjusted which is perhaps the only work that employed testbed-based experimentation. Simulation-based experimentation is becoming more and more popular in the research community because of the difficulty of deploying and the challenges of transportation, cost, scalability, etc., that come with testbed-based experimentation. A number of studies using simulations to examine the impact of choice of value of NTT on the performance of AODV could be found. An overview of these reports is provided in the following paragraphs.

A method for increasing the throughput of an ad hoc network by lowering the number of routing-related control packets has been developed by Kim and Chung [15]. They also showed how to figure out NTT

Hong and Lee [16] demonstrated the vital role of NTT in lowering the quantity of AODV control packets; they utilized the QualNet network simulator in the experiment. They claim that the AODV RFC's default NTT value of 40 ms does not entirely reflect dynamic topology in wireless ad hoc networks. They proposed an AIAD (additive increase additive decrease) strategy for regulating NTT to minimize flooding of control packets. They used the CP_AODV (control packet minimized AODV) algorithm that offers significant improvements in terms of the number of data packets received by the destination, the throughput, the amount of energy consumption, and the number of control packets when compared to the modified AODV with the timestamp and the traditional AODV.

Raju and Setty [17] introduced an improved AODV called "Fuzzy Based Node Traversal Time AODV (FBNTTAODV)" using the QualNet simulator where the number of nodes (nnodes) and speed are input variables, while NTT is an output variable. They also stated that NTT should not be a constant value defined in the AODV RFC but rather adjusted to the network conditions.

Jain and Shrivastava [18] using a fuzzy logic controller in combination with the QualNet 6.1 simulator, developed a solution for optimizing the NTT value of the AODV routing protocol. Node mobility and transmission power are considered input variables in their fuzzy logic control approach, while NTT is used as an output linguistic variable. The results obtained through manual and simulation show that fuzzy-based NTT outperforms nonfuzzy-based networks regarding Routing Overhead, average Packet Delivery Ratio, and average Throughput. They concluded from their findings that the value of NTT should not be fixed. Instead, the value of NTT should be set by a fuzzy logic controller that gives better results than the default value.

Kumar et al. [19] using the OPNET simulator, attempted to dynamically compute the value of NTT by taking input variables for fuzzy logic as the speed of nodes and network size. The simulation results found that varying NTT with the network size and speed plays a significant role in the performance of MANETs. According to their simulation results, the average Throughput for AODV and FBNTTAODV with 50 nodes was 41,265 and 43,178, respectively. Based on the findings, they concluded that FBNTTAODV outperforms AODV.

Raju and Setty [20] work focused on the IETF draft of AODV, which emphasizes that selecting the default parameter values influences the protocol's performance and that their values must be selected with network behavior in mind. Using the NS-2 simulator and an artificial neural network approach, they proposed an NNBNTTPEAODV. From the simulation results, they suggested that the value of NTT should be changed to make MANETs work better.

Naik et al. [21] used an NS-3 network simulator (version 3.13) on a Linux operating system (CentOS) to examine the AODV protocol performance. They replaced the AODV protocol's default parameter values with the new ones for the simulation. They employed a random waypoint mobility model for node mobility. Furthermore, they set the value of NTT to 50 ms and discovered that the modified AODV protocol performed much better than the original [15].

However, no work related to analysis of the effect of variation in the value of NTT on the performance of the AODV routing protocol could be traced during the literature survey until recently. However, the co-authors the work [15], recently reported an analysis of the performance of AODV in an ad hoc network of linear topology by varying values of NTT which is perhaps the first of its kind. The analysis was done for the case of the presence of Hello messages as well as for the case of the absence of Hello messages. They found that the choice of NTT-value had a significant effect on the performance of the AODV routing protocol. The co-authors of the work [15], were motivated to extend the experiment to investigate ad hoc network having large number of nodes forming a more complicated topology as compared to that of a linear one. In this paper, we have analyzed the performance of the AODV in a wireless ad hoc network using two different cases (with and without Hello messages) in a grid topology of 25 nodes using an NS-3 network simulator. The remainder of the paper is structured as follows: Network topology is provided in Section II. Section III provides simulation parameters. Section IV provides results and discussion, followed by the conclusion and future work in section 5.

II. NETWORK TOPOLOGY

Fig. 2, shows a static wireless ad-hoc network with a grid topology of 25 nodes. In this grid network, nodes 0, 5, 10, 15, and 20 are the source nodes, denoted as S1, S2, S3, S4, and S5. Similarly, nodes 4, 9, 14, 19, and 24 are the destination nodes, denoted by D1, D2, D3, D4, and D5. Data is being transferred from S_iS_i to D_jD_j where *i* is 5, 10, 15, 20, and *j* is *i* + 4.

A. Performance Metrics

The following metrics were used to investigate the performance of the AODV routing protocol in the scenario mentioned above.

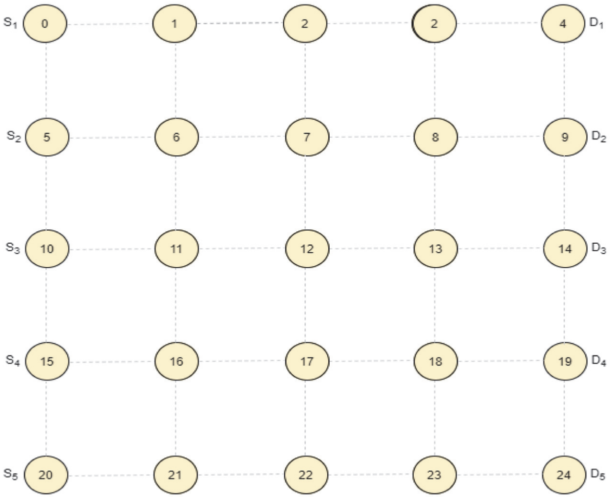


Fig. 2. Nodes in a grid topology.

Route Error Overhead (REO) is defined as the number of error control packets generated by AODV as a result of link breakage in active routes [15].

Routing Overhead (RO) is defined as a number of routing packets that are transmitted by the nodes for the discovery and maintenance of the routing path for data transfer. The set of routing packets includes RREQ, RREP, RREP ACK, RERR, and Hello message [15].

Normalized Routing Load (NRL) is defined as the ratio of the total size of routing overhead (including RREP, RREQ, RERR, and Hello message) to the total size of received data packets [15].

$$Normalized\ Routing\ Load = \frac{Total\ Size\ of\ Routing\ Overhead\ in\ bits}{Total\ Size\ of\ Received\ Data\ Packets\ in\ bits}$$

Average Hop Count (AHC) is defined as the ratio of the total number of hops involved in delivering packets to the total number of received data packets [15].

$$Average\ Hop\ Count = \frac{Total\ Number\ of\ Hops}{Total\ Number\ of\ Received\ Data\ Packets}$$

Packet Delivery Ratio (PDR) is defined as the ratio of the total number of received data packets to the total number of transmitted data packets [15].

$$PDR = \frac{Total\ Number\ of\ Received\ Data\ Packets}{Total\ Number\ of\ Transmitted\ Data\ Packets} * 100$$

Throughput is defined as the ratio of total bits of received data packets to the time difference between the last received data packet and the first transmitted data packet. To obtain the Throughput in kbps, it is divided by 1024 [15].

$$Throughput\ (Kibps) = \frac{Total\ Number\ of\ Received\ Data\ Packets\ in\ bits}{(Last\ Received\ Data\ Packet\ Time - First\ Transmitted\ Data\ Packet\ Time) * 1024}$$

Average End-to-End Delay (AEED) is defined as the ratio of the sum of all delays experienced by delivered data packets to the total number of received data packets by the destinations [15].

$$Average\ End - to - End\ Delay = \frac{Sum\ of\ All\ Delays\ Experienced\ by\ Delivered\ Data\ Packets}{Total\ Number\ of\ Received\ Data\ Packets}$$

III. SIMULATION PARAMETERS

The simulation parameters are listed in Table 1. The computer system used is a Dell Vostro 3741 with a 3.60 GHz Intel Core i3-9100 processor, 8 GB of RAM, and Ubuntu 20.04 LTS. Fig. 3 illustrates the time windows for the simulation's start and end and the On-Off Application used in our programme [15].

Table 1. Simulation parameters

Parameter	Value
Simulator	NS-3.33
Number of nodes	25
Application	On-off application
Application data rate (kbps)	16
Traffic	CBR
Packet size (payload)	512 bytes
Routing protocol	AODV
Transport layer protocol	UDP
MAC mode	Ad-hoc
Physical standard	IEEE 802.11b
Propagation loss model	Log distance propagation loss model
Propagation delay model	Constant speed propagation delay model
Reference loss (dBm)	40.0459
Simulation time (s)	150, 250, 350, 450, and 550
NTT (ms)	10, 20, 30, 40, and 50

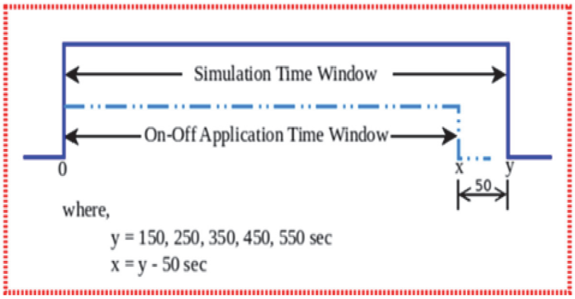
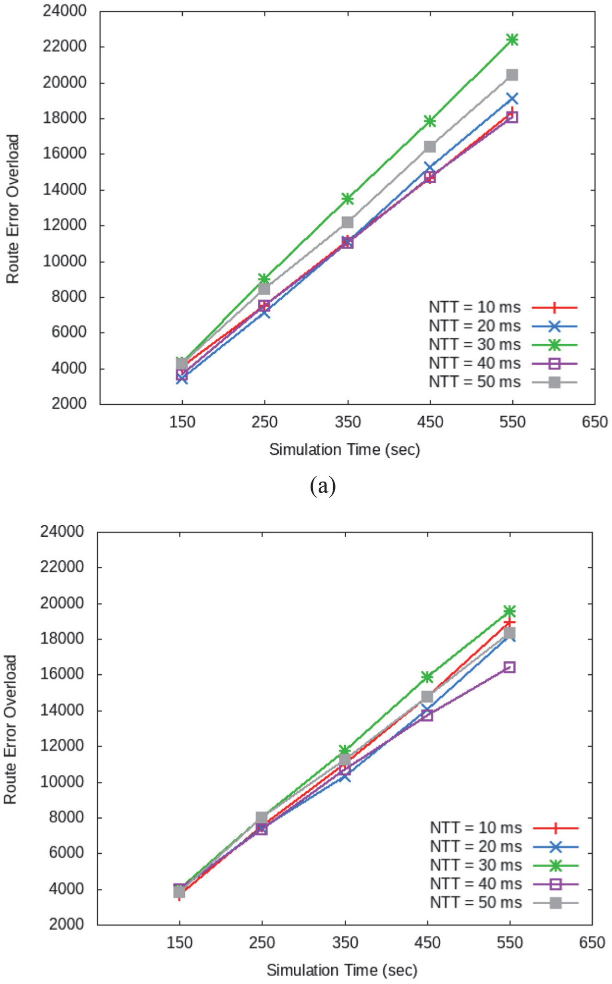


Fig. 3. Different time windows.

IV. RESULT AND DISCUSSION

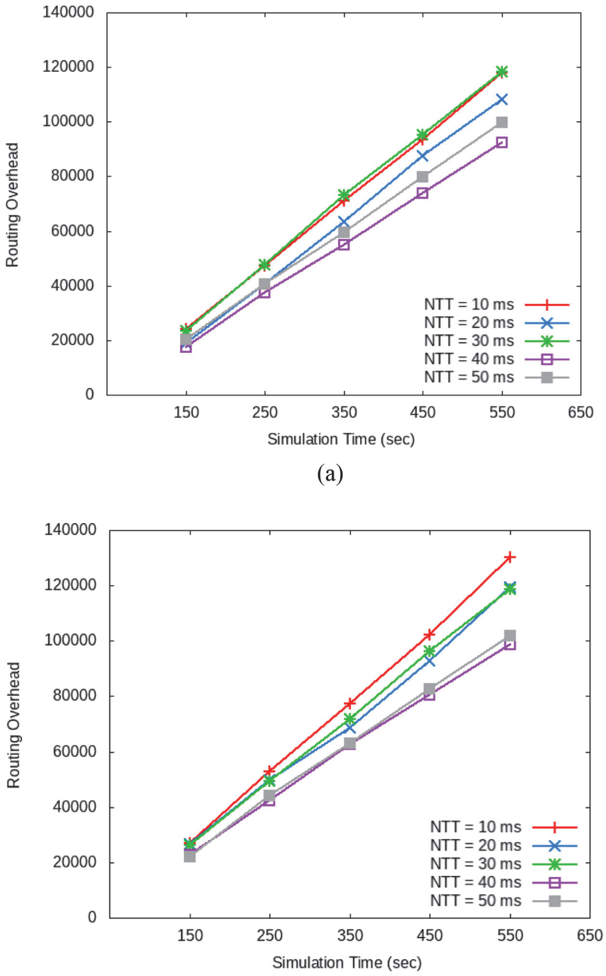
Fig. 4(a) and 4(b) show the dependence of REO on simulation time for different values of NTT for Case 1 and Case 2, respectively. As shown in Fig. 4, REO increases with the increasing simulation time. The grid of nodes could be treated as parallelly aligned five rows of five nodes each with source and destination at the two ends of each such row. During simulation, each such row experiences a load of control packets from the neighboring rows which result in link breakages, followed by phases of the search for fresh routes. This is repeated again and again as data continue to be generated by the source nodes. Each such link breakage may contribute to the generation of route error messages. As



(a)

(b)

Fig. 4. Variation of route error overhead with simulation time. (a) Case 1 (without AODV Hello message). (b) Case 2 (with AODV Hello message).



(a)

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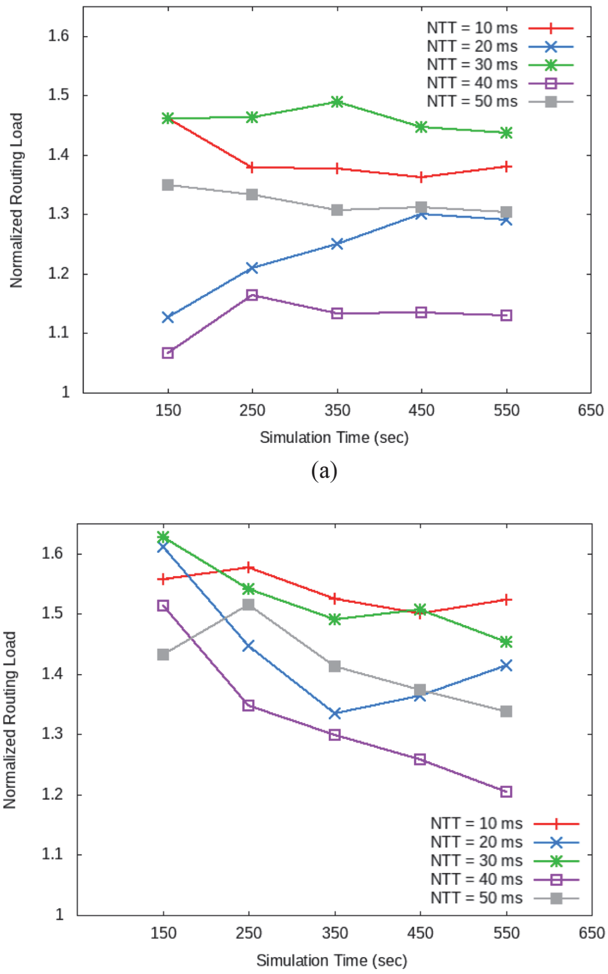
Fig. 5. Variation of routing overhead with simulation time. (a) Case 1 (without AODV Hello message). (b) Case 2 (with AODV Hello message).

simulation time increases, chances for more link breakages, and more route error messages would be generated resulting in increased REO with simulation time. Link breakages are followed by fresh route searches.

The time taken by such fresh route searches is governed by the intricacies of the combination of states of various links and flows in the grid topology along with the choice of the value of NTT which makes a bit plausible to interpret the variation of REO with NTT. REO gets slightly reduced in Case 2 which may be attributed to the presence of Hello messages which perhaps might be avoiding certain chances of the link being declared broken in Case 1.

Fig. 5(a) and 5(b) depict the dependence of RO on simulation time for various values of NTT for Case 1 and Case 2, respectively. As mentioned in the section of REO for the given grid topology, rows of nodes experience a load of certain control packets from neighboring rows. Frequent link breakages and phases of fresh route searches result in generation and transportation of more and more control packets related to routing which result in an increased amount of routing overhead with an increase in simulation time. It is observed from Figs. 4 and 5 that routing overhead is 4 to 5 times the corresponding route error overhead. Route overhead is attributed to route request and route reply messages in addition to route error messages. Intricacies of interaction between different links across different paths along with states of different links governed by the choice of NTT makes it practically not plausible to interpret explicitly the dependence of RO on the choice of NTT.

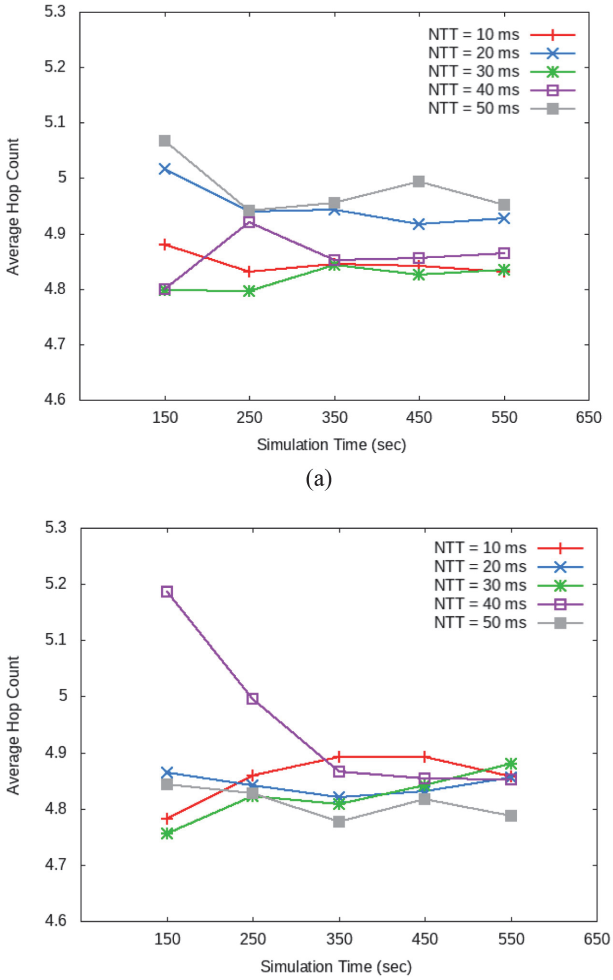
Fig. 6(a) and 6(b) show variation of NRL with simulation time for different values of NTT in Case 1 and



(a)

(b)

Fig. 6. Variation of normalized routing load with simulation time. (a) Case 1 (without AODV Hello message). (b) Case 2 (with AODV Hello message).



(a)

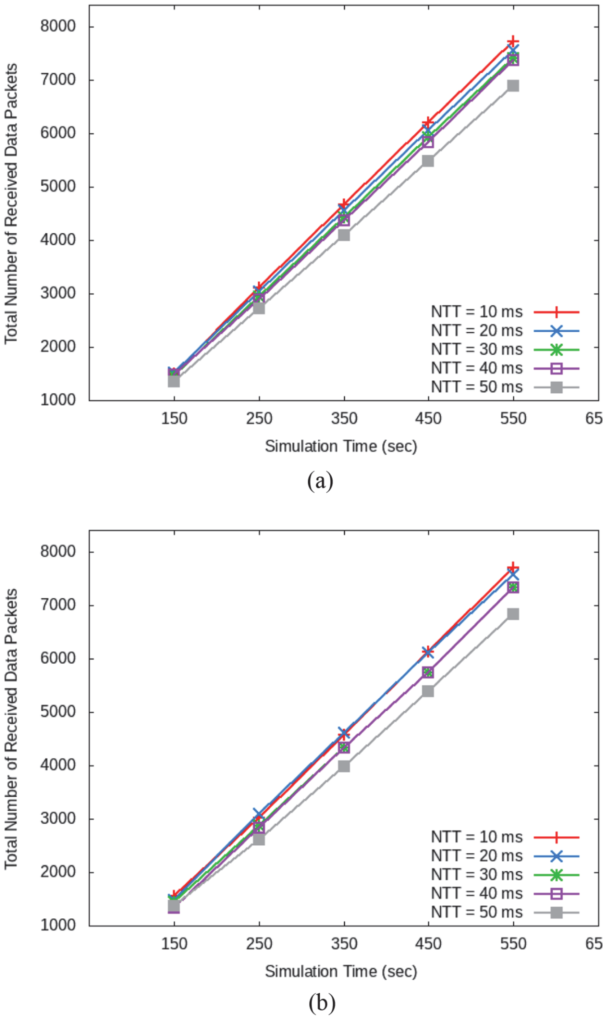
(b)

Fig. 7. Variation of average hop count with simulation time. (a) Case 1 (without AODV Hello message). (b) Case 2 (with AODV Hello message).

Case 2, respectively. The presence of Hello messages in Case 2 may be contributing additionally to routing overhead being experienced in Case 1. Though NRL has different simulation time as well as NTT, no explicit pattern is observed. However, as observed in Fig. 5(b), RO is more in the case of NTT = 10 ms compared to other values of NTT; therefore, the NRL is more for NTT = 10 ms, which is due to the very definition of NRL, which is defined as the ratio of the total size of routing overhead in bits. It is worth mentioning here that the size of routing control packets varies from 240 to 416 bits, whereas the size of received packets is 4320. At the same time, as the scenario of states of different flows, links, and routes might get drastically changed from the transportation of certain new packets as compared to that for the preceding packets, the number of additional routing control packets being generated may not be necessarily proportional to the number of data packets being generated.

Fig. 7(a) and 7(b) show the dependence of AHC on simulation time for various values of NTT in Case 1 and Case 2, respectively. AHC in the present grid topology is lying in the range of 4.7 to 5.2 whereas it is reported to be 4 in the case of linear topology [15]. This may be attributed to, as previously mentioned, frequent link breakages and the establishment of fresh routes including many paths not confined to the horizontal rows of the grid only. Rather, certain packets of a flow corresponding to source and destination nodes of a horizontal row might be following nodes at the intersection of the grid also. In Case 2, by and large, AHC is lower than in Case 1. This may be due to the presence of Hello messages. Hello messages may be favoring the selection of routes that comprised more and more horizontal sub-paths.

Fig. 8(a) and 8(b) show dependence of the Total Number of Received Data Packets on simulation time



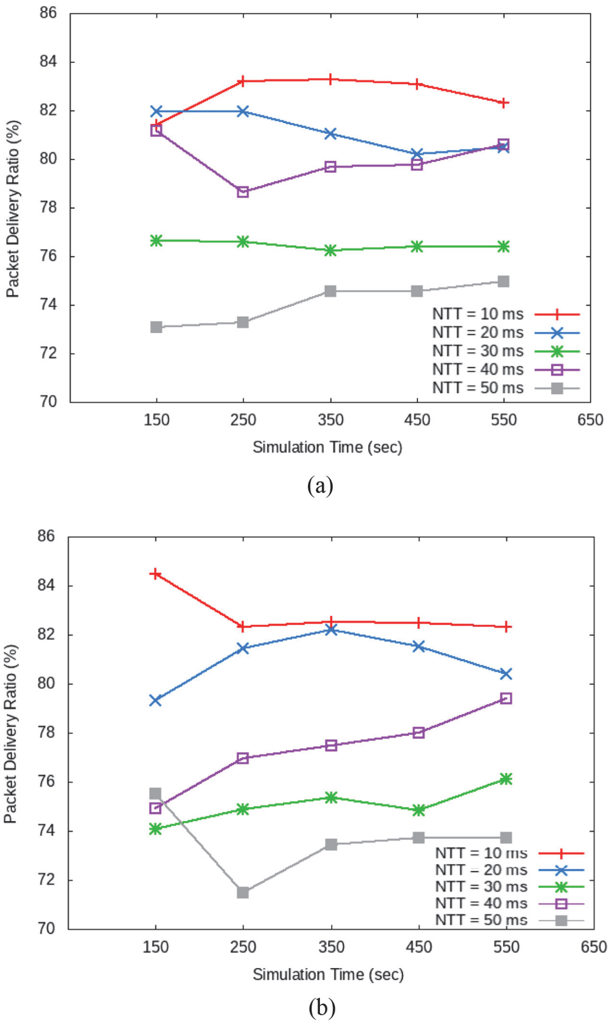
(a)

(b)

Fig. 8. Variation of total number of received data packets with simulation time. (a) Case 1 (without AODV Hello message). (b) Case 2 (with AODV Hello message).

with NTT as a parameter. It is evident that the Total Number of Received Data Packets increases linearly with an increase in the simulation time. As ON-OFF application generates data at a constant rate of 16 Kbps, increased simulation time results in proportionally increased number of packets generated thereby causing proportional increase in the Total Number of Received Data Packets. The maximum value of the Total Number of Received Data Packets is close to 8000 when the simulation time is taken as 550 sec. In previous work related to a single row of five nodes (linear topology), the Total Number of Received Data

Packets was reported as 2000. As the grid topology of the present work could be thought of as five above mentioned rows of linear topology parallel to each other, in the absence of any interaction between nodes of adjacent rows, the Total Number of Received Data



(a)

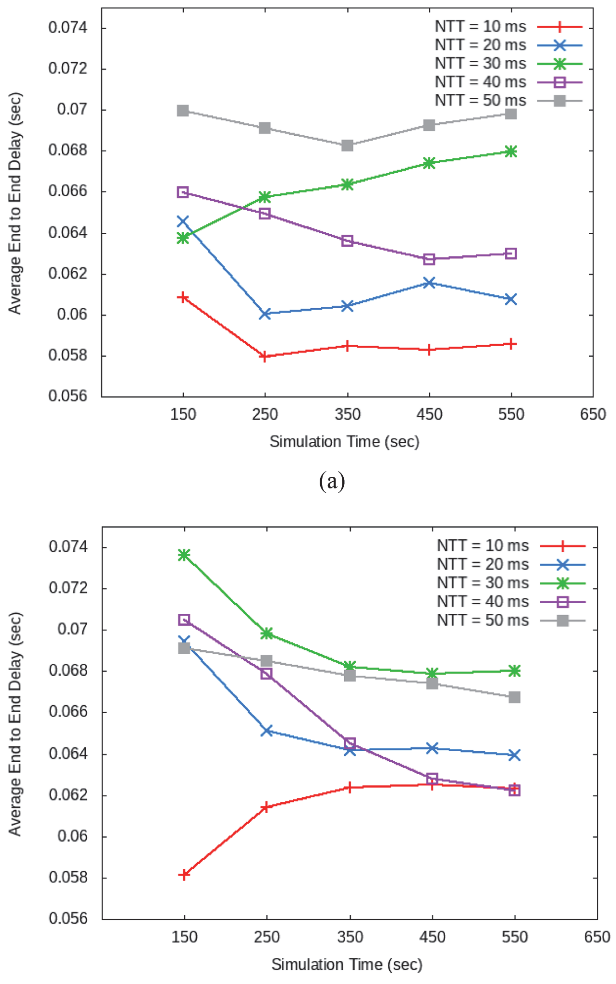
(b)

Fig. 9. Variation of packet delivery ratio with simulation time. (a) Case 1 (without AODV Hello message). (b) Case 2 (with AODV Hello message).

Packets would be five times the Total Number of Received Data Packets reported in the previous work [15], i.e., 10,000. However, the lesser value of the Total Number of Received Data Packets in grid topology may be attributed to the stress experienced by rows of nodes from other rows which results in the loss of certain packets. The presence of Hello messages has no effect on the Total Number of Received Data Packets.

Variation of PDR with simulation time is shown in Fig. 9(a) and 9(b) for Case 1 and Case 2, respectively. PDR in the grid topology is in the range of 70% to 85% whereas it was reported as 100% in the previous work [15] for a single row of nodes. Loss of packets in grid topology results in the reduction in PDR. It is also evident that PDR has little dependence on the presence of Hello messages.

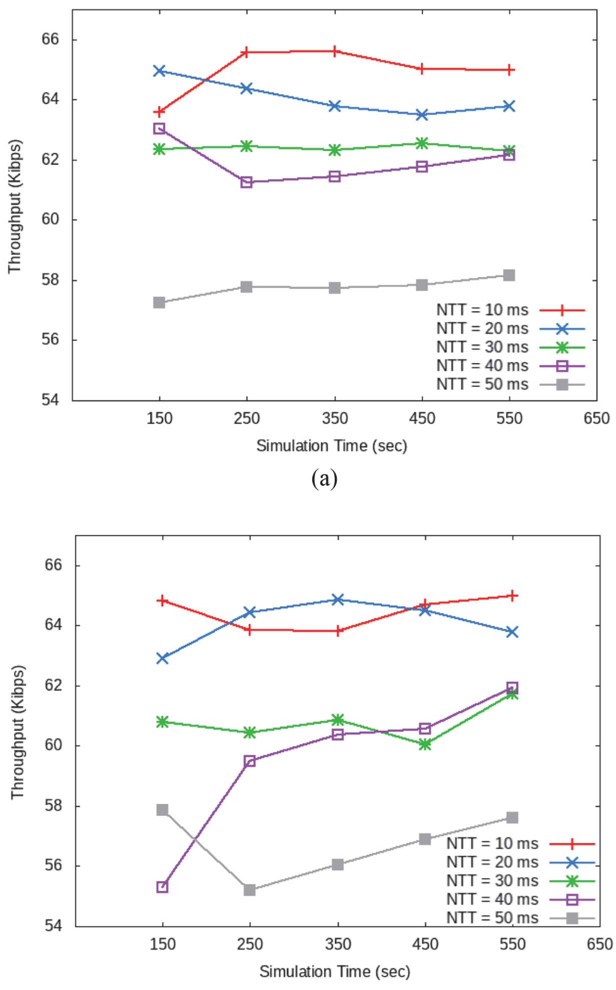
Fig. 10(a) and 10(b) show the dependence of AEED



(a)

(b)

Fig. 10. Variation of average end to end delay with simulation time. (a) Case 1 (without AODV Hello message). (b) Case 2 (with AODV Hello message).



(a)

(b)

Fig. 11. Variation of throughput with simulation time. (a) Case 1 (without AODV Hello message). (b) Case 2 (with AODV Hello message).

with simulation time with NTT as a parameter. AEED is found lying in the range of 0.056 to 0.074 seconds for the grid topology whereas it was reported to lie in the range of 0.0203 to 0.0211 seconds [15] for a single row of nodes. Frequent link failures followed by phases of fresh route discoveries result in higher AEED. AEED is comparatively lower in Case 2 as compared to that in Case 1. It is substantiated by reduced average hop count in the presence of Hello messages as discussed previously.

Variation of Throughput with simulation time is shown in Fig. 11(a) and 11(b) for Case 1 and Case 2, respectively. NTT is taken as a parameter starting from the value of 10 with a step size of 10. In both cases, by and large, Throughput is getting reduced with an increase in NTT. This may be attributed to the increased duration of search for fresh routes with a higher value of NTT. It is evident from Fig. 11(a), that for a simulation time of 550 seconds with NTT 50, Throughput is close to 58 kbps.

The corresponding throughput in the previous work [15] was reported as close to 16.5 kbps, which one can be estimated to correspond to throughput in the grid topology of the present work as five times 16.5 kbps that is equal to 82.5 kbps, which is much higher than 58 kbps. In fact, figure of 82.5 kbps as Throughput is estimated under the assumption that all the rows of the grid do not have any effect on each other. On the contrary, the rows of the grid topology interact with each other and experience stress due to participation in finding routes for data of other rows or data transportation of other rows.

V. CONCLUSION AND FUTURE WORK

In the present work, the effect of choice of NTT on the performance of AODV routing protocol in a grid topology of five rows, each consisting of five nodes, has been investigated having taken into account the absence and presence of Hello messages. REO increases with increasing in simulation time. The presence of Hello messages slightly reduces REO. An increase in simulation time increases RO wherein RO is four to five times that of the corresponding REO. Though NRL varies with variation in simulation time as well as NTT, no explicit pattern is observed. However, the presence of Hello messages results in increased NRL. AHC in grid topology is more as compared to that in a linear topology of a same number of nodes which a row of the grid topology consists of. By and large, AHC in presence of Hello messages is lower than that in the absence of Hello messages. The Total Number of Received Data Packets is found to increase linearly with an increase in simulation time which has no noticeable effect in presence of Hello messages. The Total Number of Received Data Packets in the present grid of five rows, each having five nodes, is lower than that estimated as five times the Total Number of Received Data Packets in the corresponding linear topology of five nodes. Loss of packets in grid topology results in reduction in PDR as compared to its corresponding linear topology of five nodes. It is also observed that PDR does not have any noticeable dependence on the presence of Hello messages. The AEED is reduced in the presence of Hello messages in grid topology. It is also observed that AEED in grid topology is significantly higher than that in its corresponding linear topology of five nodes. Throughput in grid topology, by and large, is observed to reduce with an increase in NTT. As compared to Throughput estimated as five times the Throughput of the corresponding linear topology of five nodes, the Throughput of the grid topology is found to be approximately 30% less for the scenario of combined high simulation time and high NTT. No explicit relationships between certain metrics with simulation time as well as NTT could be drawn due to intricacies involved in the form of a combination of states of various links and flows in the grid topology. In the future, grid topologies of two, three, and four rows of five nodes each could be investigated to have detailed and better understanding of how rows interact with each other so that the effect of NTT, as well as simulation time on performance metrics, could be explained further.

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