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Improving Throughput in Mobile Ad-hoc Networks MANETs Based on Spatial-based Multiple-Inputs Multiple-Outputs MIMO Solution using Simulation Approach

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ABSTRACT

In wireless wide area networks (WWANs), Even though many access points (APs) are deployed for full coverage, an in ignorable number of devices cannot gain services. To solve this problem, the termed mobile ad-hoc networks (MANET) are proposed. A mobile ad-hoc network is an Infrastructure-less, self-organizing, and self-configuring network that allows mobile devices to cooperate with each other in order to gain permanent access. The accelerating development of real-time applications such as Internet of Things (IoT) adds new challenging goal which is providing high throughput through MANETs. This study aims to achieve the aforementioned goal by proposing Spatial Multiplexing-based MIMO solution. In Spatial Multiplexing-based MIMO, each transmitting antenna can independently transmit a unique data stream, which expected to increase total throughput. Ad-hoc on-demand distance vector (AODV) and destination sequenced distance vector (DSDV) routing protocols were selected as they are the most widely used reactive and proactive routing methods used with MANETs. We explain the proposed solution, then review results for feasibility assessment under four different scenarios using Network Simulator software. Based on the obtained results, the proposed solution led to improve throughput successfully when both protocols are assigned, however, throughput with AODV is much better under all conducted scenarios.

Keywords: *MANETs, AODV, DSDV, Spatial Multiplexing-based MIMO, Throughput*

1. Introduction

The Cisco annual Internet Report 2020 anticipated that two-thirds of the world population will be able to access Internet before the end of 2023 [1]. A worth-mentioning expectation that the number of devices linked to the Internet will exceed the world population by over three times. 50 % of these devices will be those incorporating what is called machine-to-machine (M2M) modules. Networks that links such devices are referred to as Internet-of-Things (IoT). In IoT, devices can establish direct connections between each other dependently without the need to intermediate units such as base stations, which is similar to case in mobile ad-hoc networks (MANETs). Based on this fact, one can conclude that the use of MANETs in IoT becomes inevitable. [2]. A MANET can be described as a topology-less wireless environment where a number of mobile nodes cooperate to exchange data. A node within this wireless environment can also works as a router rather than a simple transceiver. In a MANET, although a node can move freely, it can easily communicate even with other nodes that are out of its range, simply via cooperating with its neighbours. [3]. In a simple MANET, if a node wants to communicate with another that is faraway of its domain, it should ask assistance from an intermediated node, that is, the originating node first sends its data to the intermediate node which in turn forwards it to the intended destination (receiving node). The accelerating evolution of real-time applications in terms of Internet of Things (IoT) creates new challenging goal, that is developing a high speed MANET. Many research proposals aimed to achieve the aforementioned goal. Below are addressing of some of these research proposals found in the literature. R. Ohmiya et al. [4] searched to improve throughput quality by using three different ad hoc network configurations. They introduced a cooperative technique in order to achieve their goal. They came up with a conclusion that only interference among users, SNR, and coverage distance should be taken into account. Sumiko Miyata et al. [5] proposed an optimum AP selection method to increase throughput within a prescribed perimeter while maintaining a regular average of throughput for those users who penetrate that perimeter recently. They recommend to apply this method a tolerable throughput threshold for satisfying results. Tianran Luo et al. [6], [7] studied the positioning of a single mobile user and its potential effects on throughput. They came up with a conclusion that optimal position takes place when a mobile user lies under capture effect or dynamic back-off time. J. Xie and T. Murase. [8] introduced an interactive positioning method to achieve high throughput in a multiple user mobility environment. Although, this method led to satisfying results, it has a long completion time and large overhead. Thus, it is considered as not an efficient way. A. Argyriou [9] seeks to improve the throughput by involving different modulation techniques, specifically, single carrier (SC), high-frequency bonding, and orthogonal frequency division (OFDM) modulation techniques. Sandip et al. [10] proposed a method to improve the performance at the level of transmission control protocol (TCP) using different congestion management strategies. The proposed method involves several QoS approaches that leads to increase the throughput, such as admission control, calculation of the transmission opportunity (TXOP), and scheduling approach. Zhiqun et al. [11] focused on bandwidth allocation strategies of wireless LANs, specifically IEEE 802.11ac. They provided Markov chains in non-saturated situations; however, they only examine ideal channel conditions where scheduling approach that seeks to reach high throughput are not included. Mounir et al. [12] proposed a method for simultaneous transmission. The method gives acceptable transmission parameters for selected customers, and thus be able to allocate alternative transmission parameters in order to improve user throughput. The work in this paper aims to improve throughput in MANETs proposing spatial-based MIMO solution in which different data streams can be transmitted independently via multiple antennas. Details of the proposed solution is provided at the rest of this article.

2. Routing Protocols for MANETs

In networking, one of the main functions of the network layer is routing. It can be defined as the mechanism of establishing or selecting a suitable path for sending data packets. For routing to take place, there must be an assigned protocol to follow. A reliable routing protocol must be able to select a suitable path among several potential source-to-destination paths, and thus transport data packets correctly to their final destinations [13]. Routing becomes more difficult when working at mobile environments due to the continuous variation of nodes positions, which is the exact case in MANETs. In such environments, Routing protocols are either proactive, i.e., updates their routing information frequently or, reactive, i.e., be able to establish a correct rout rapidly when it is required. In sum up, reactive routing protocols or on-demand routing protocols are the MANETs routing protocols that have been developed based on the concept of establishment when needed. This routing protocol follows two main steps. In the first step, sender node examines its temporary memory for available route, if there is no available route, it goes into route discovery process. In the second step, a route maintenance process is applied when there is a link failure. Ad-hoc On-demand Distance Vector (AODV) and Dynamic Source Routing (DSR) are two examples of reactive routing protocols. AODV is selected in this study since it is the most widely used reactive routing method [13]. An AODV contains routing table that saves temporary information of available routs. This routing information becomes expired after a specific time if it is not used. In AODV, there is three possible routing messages which are: Route Request (RREQ), Route Reply (RREP), and Route Error (RERR). A node goes into route discovery process by sending an RREQ to its adjacent nodes (multicast RREQ message). Each of the adjacent nodes record the original source of this message and forwards it to its adjacent nodes as well. This process is lasted until the RREQ reaches its Intended destination and consequently a suitable route is established. This process is called route request. The destination node sends back a RREP to the source node on the established route. This process is called request reply. Any of the intermediate nodes can send back an RREP immediately when it receives RREQ if it still keeps temporary routing information to the intended destination, which helps to avoid complete route discovery process, and thus reducing the possible delay. Finally, the two nodes can begin data exchange. If an unexpected route failure appears suddenly, an RERR is sent to the source node by the node that detected the fault through other intermediate nodes, which finally leads to delete the broken route. The RERR contains information of the intended destination that became unreachable. Consequently, route discovery process begins again [13]. In proactive routing protocols, each node can obtain sufficient routing information using its own routing table, hence it is sometimes referred to as table-driven routing protocols. To keep fresh routing information, tables are updated periodically. A worth-mentioning advantage of these routing protocols is its small delay as it works based on frequently updated routing tables, however, it might lead to decrease throughput as there is a potential increase in the overhead due to the increased control signals used in the process of tables updating. Another drawback of this routing method is its non-suitability to work with huge networks due to potential huge entries in each node's table. Examples of proactive routing protocols are destination sequenced distance vector (DSDV) and optimized link state routing (OLSR). DSDV is selected in this study since it is the most widely used proactive routing method [6]. In DSDV, there is a continuous need to update routing tables as there is no fixed topology due to mobile environment. Following are the steps to create and update routing tables:

1. Each node recognizes its adjacent nodes by sending HELLO message and receiving REPLY message.
2. As adjacent nodes are 1-hop distant, a routing table with 2-hop entries is established by each node.
3. Each node broadcasts its own routing table to the current adjacent nodes, consequently, a least hop counts routing table to all potential destinations is established in each node.
4. Broadcasting is performed frequently for routing tables update.
5. Nodes cooperate in building paths, and relay each other's packets to intended destinations.
6. A node applies the next steps to update its routing table:
    a. Routes with recent sequence numbers are utilized, routes with older sequence numbers are omitted.
    b. For identical sequence numbers, a route with the better hop-metric is chosen. [14].

3. Spatial Multiplexing-Based MIMO

Basically, Multi-input, Multi-output, or simply MIMO is the technology that seeks to enhance performance of wireless communication systems by incorporating multiple antennas at sender side, receiver side, or both sides. In fact, MIMO basically seeks to overcome the effect of multipath phenomenon in wireless channels using the concept of space division of multiple antennas which known as spatial diversity. Later, a new vision appears that seeks to exploit multipath phenomenon which known as spatial multiplexing. In spatial multiplexing, a number of data streams can be transmitted simultaneously over wireless channel by exploiting its multiple paths, which potentially leads to bit rate increase. Compared to some widely spread multiplexing schemes, such as frequency division multiplexing (FDM) and time division multiplexing (TDM), spatial multiplexing shows many attractive pros. For example, in spatial multiplexing, a number of signals can be sent at the same time and over the same frequency band. It also can increase the bit rate without raising the bandwidth [15]. The input stream intended for transmission first undergoes an encoding process before being separated into group of individual streams which are modulated and then transmitted using a unique antenna for each. At the receiver side, although a bulk of all transmitted streams is received by each antenna, each individual stream is going to be recognized using the so-called spatial modulation (SM) encoder. Later, each recognized stream undergoes demodulation process before being combined using parallel-to-serial unit [15]. For $N \times N$ spatial-multiplexing MIMO system, throughput can be increased linearly by increasing the number of antennas. Due to its ability of sending many signals over the same bandwidth, one can observes that spatial multiplexing could lead to an enhanced spectrum efficiency in terms of bit per unit hertz [15].

4. Materials and Methods

4.1 *Simulation Tools and Environment*

In this paper, Network Simulator 3 (NS-3) was used to measure the average throughput [16]. NS-3 is an open-source simulator that relies on C++. Default C++ codes were modified to estimate average throughput. Default C++ codes were also modified to incorporate the proposed MIMO solution. NetAnim was used as the graphical user interfaces (GUI) that enabling network design visually. Simulation was performed in Oracle VirtualBox's graphical user interface version 7.0.6 which is an open-source virtual machine. The operating system installed in the virtual machine is Ubuntu 18.04 (64-bit) with 25 GB of disc space and 3 GB of RAM.

4.2 *Workflow*

The flowchart shown in Figure 1 describes the workflow. In step 6, the source code is modified in order to compute the average throughput and incorporate the MIMO solution. Figures 2 and 3 provide snapshots of the modified codes.

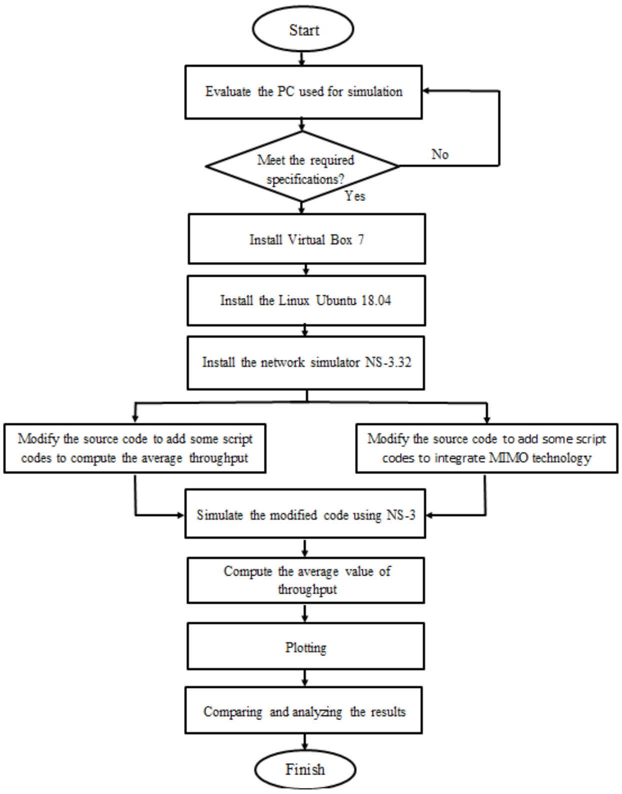

Figure 1: Flowchart describing the workflow

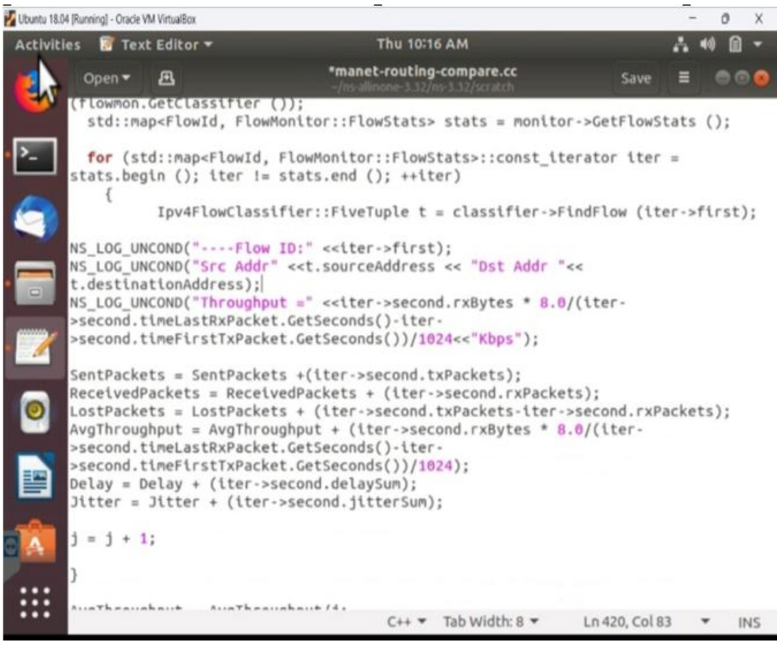

Figure 2: Snapshot of the modified source code for throughput computation

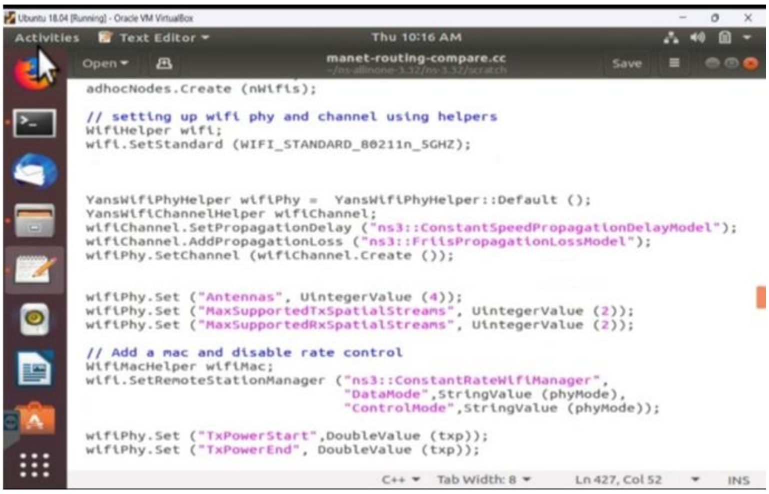

Figure 3: Snapshot of the modified source code that enables MIMO incorporation

4.3 Simulation Setup

This section is divided into two parts. In the first part, simulation is prepared for evaluating throughput using single-input, single-output (SISO) transmission, whereas in the second part, simulation is prepared for evaluating throughput using the proposed spatial-based MIMO solution. Further details on the simulation setups of both parts are provided below.

4.3.1 Simulation setup for part 1

In this part, the simulator was adjusted to run for 100–300 simulated seconds. The number of nodes is 25. Nodes' movement was set to the Random Way Point Mobility Model. An average speed of 20 m/s was set to each node with no pause time inside a prescribed zone of 300 m x 1500 m . The Wi-Fi was set to ad hoc mode considering Friis loss model. The mode of propagation was set to omnidirectional with SISO transmission. The transmitted power was set to 7.5 dBm. By default, there are 10 source-sink data pairs delivering user datagram protocol (UDP) data at a rate of 2.048 kb/s for each. This is done over a rate of 64-byte packets per second. Table 1 displays the parameters used in this part and their descriptions.

Table 1. Simulation parameters for part 1

Parameter	**Value/Description**
Area	*300 x 1500 m^2*
Channel Type	Wireless channel
Simulation Time	(100-300) s
Mobility Speed	20 m/s
PHY Layer Model	IEEE 802.11b
MAC Layer Protocol	802.11
Antenna	Omni directional antenna
Antenna Connection	SISO
Modulation	Dsss
Number of Nodes	25
Routing Protocol	AODV and DSDV
Mobility Model	Random way point
Packet Size	64-byte
Data Rate	2.048 Kbps
Paused Time	0s

4.3.2 Simulation setup for part 2

In this part, the simulator was adjusted to run for 100–300 simulated seconds. The number of nodes is 25. Nodes' movement was set to Random Way Point mobility model. An average speed of 20 m/s was set to each node with no pause time inside a prescribed zone of 300 m x 1500 m. The Wi-Fi was set to ad hoc mode considering Friis loss model. The mode of propagation was set to omnidirectional with MIMO transmission. The transmitted power was set to 7.5 dBm. By default, there are 10 source-sink data pairs delivering UDP data at a rate of 2.048 kb/s for each. This is done over a rate of 64-byte packets per second. Table 2 displays the parameters used in this part and their descriptions. The values used in both parts of simulation lie within recommended ranges reported in [17].

Table 2. Simulation parameters for part 2

Parameter	Value/Description
Area	*300 x 1500 m^2*
Channel Type	Wireless channel
Simulation Time	(100-300) s
Mobility Speed	20 m/s
PHY Layer Model	IEEE 802.11n
MAC Layer Protocol	802.11
Antenna	Omni directional antenna
Antenna Connection	MIMO
Modulation	OFDM
Number of Nodes	25
Routing Protocol	AODV and DSDV
Mobility Model	Random way point
Packet Size	64-byte
Data Rate	2.048 Kbps
Paused Time	0s

5. Results and Discussions

In this section, results are obtained, presented and analysed considering four different scenarios. All presented graphs are devoted for observing changes in average throughput during simulation time.

5.1 MIMO-free DSDV-based MANET VS MIMO-DSDV-based MANET

In this scenario, average throughput was compared when MIMO-free DSDV-based MANET, and MIMO-DSDV-based MANET are applied. Obtained results is shown in Figure 4. Although both graphs follow the same behavior, throughput in the case of MIMO-DSDV-based MANET reaches higher values. Throughput starts to increase steadily with almost 0.29 Kbps until t = 150s before starting a rapid growth until t = 250s, and finally settling at 0.6 Kbps at the end of the simulation time.

5.2 MIMO-free AODV-based MANET VS MIMO-AODV-based MANET

In this scenario, throughput was compared when MIMO-free AODV-based MANET, and MIMO-AODV-based MANET are applied. Obtained results is shown in Figure 5. Although throughput in the case of MIMO-AODV-based shows a decreasing behaviour, it reaches higher values at the entire period. It specifically commences with almost 550 kbps at t = 100s, then starts to decrease dramatically before settling at almost 83 kbps at the end of the simulation time.

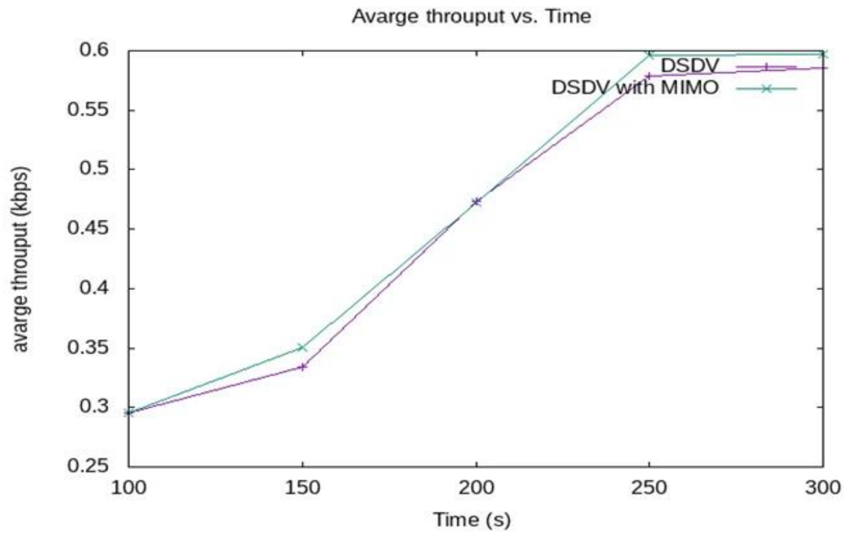

Figure 4: Average throughput, MIMO-free DSDV-based MANET vs MIMO-DSDV-based MANET

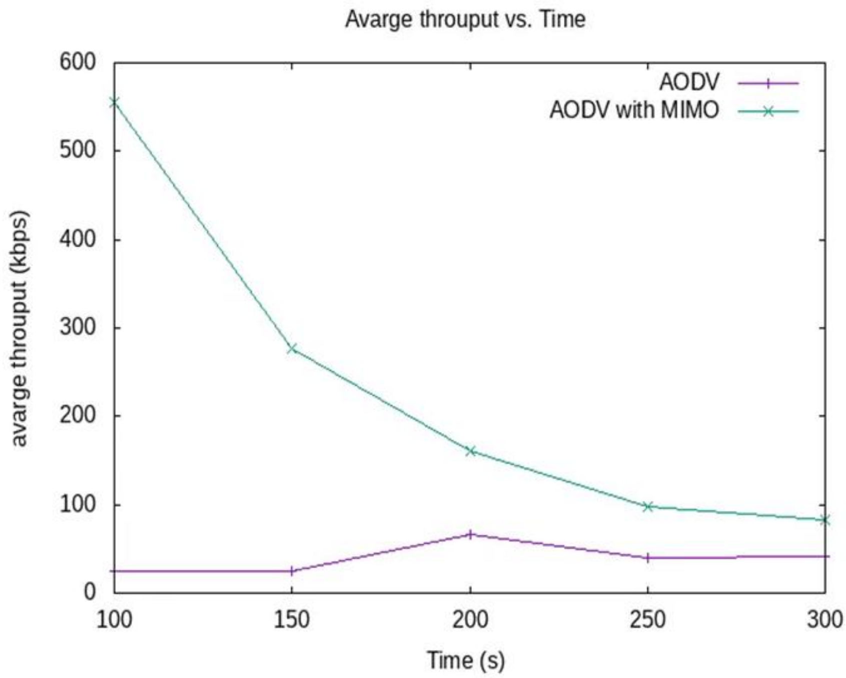

Figure 5: Average throughput, MIMO-free AODV-based MANET vs MIMO-AODV-based MANET

5.3 *MIMO-free DSDV-based MANET VS MIMO-free AODV-based MANET*

In this scenario, throughput compared when MIMO-free DSDV-based MANET, and MIMO-free AODV-based MANET are applied. Obtained results is shown in Figure 6. It is obviously seen that throughput in the case of MIMO-free AODV-based MANET reaches higher values all the time.

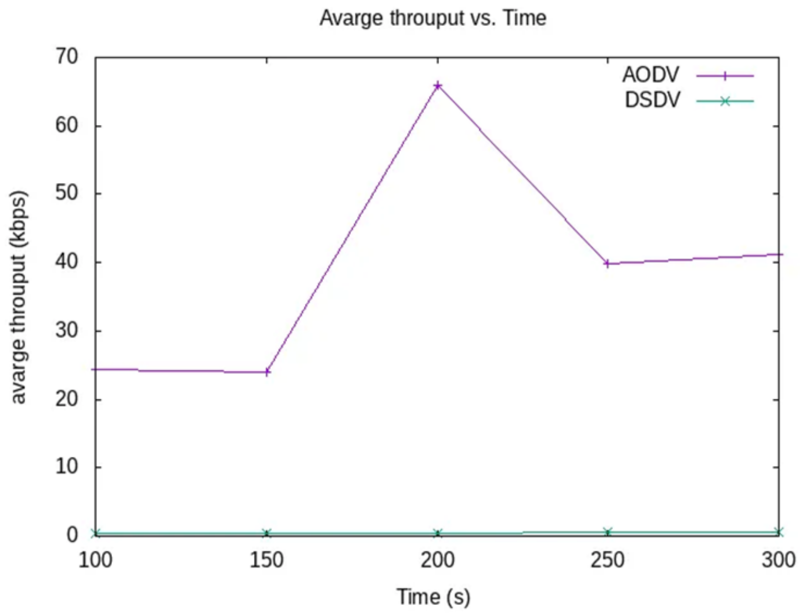

Figure 6: Average throughput, MIMO-free DSDV-based MANET vs MIMO-free AODV-based MANET

5.4 MIMO-DSDV-based MANET VS MIMO-AODV-based MANET

In this scenario, throughput compared when MIMO-DSDV-based MANET, and MIMO-AODV-based MANET are applied. Obtained results is shown in Figure 7. Although throughput in the case of MIMO-AODV-based shows a decreasing behaviour, it reaches higher values all the time.

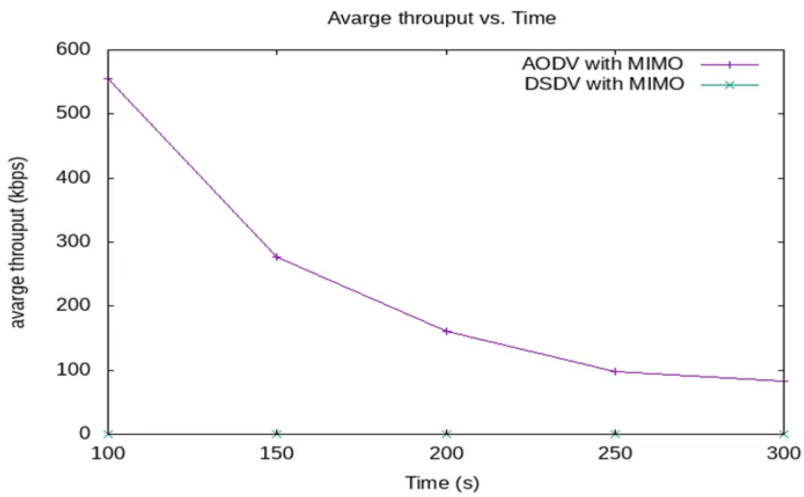

Figure 7: Average throughput DSDV and AODV with MIMO

6. Conclusions

In this paper, Spatial Multiplexing-based MIMO solution was proposed for improving throughput of MANETs. Throughput were estimated under four different scenarios: 1st is MIMO-free DSDV-based MANET versus MIMO-DSDV-based MANET, 2nd is MIMO-free AODV-based MANET versus MIMO-AODV-based MANET, 3rd is MIMO-free DSDV-based MANET versus MIMO-free AODV-based MANET, and 4th is MIMO-DSDV-based MANET versus MIMO-AODV-based MANET. Results of 1st and 2nd scenarios tell a significant improvement in the average throughput, which confirms the feasibility of the proposed spatial multiplexing-based MIMO solution. By this solution, many data streams are separated spatially and sent at the same time over the same bandwidth, which increase the spectrum efficiency in terms of bit per unit hertz.

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