An Analysis of the Performance of MAC Buffer Size for Real Time Service Support in Dense MANET Scenarios

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***Abstract* - A Mobile Ad-hoc Network or (MANET) which uses movable wireless devices without infrastructure requirements is the most dynamic communication network in use today. A MANET has a group of mobile nodes or stations connected in an auto-configured and self-healing wireless network. The stations attached to a MANET change rapidly and each act as a router by forwarding packets to other stations in the MANET. The characteristics of the supported service (real-time or bulk download) places requirements on the underlining network in terms of delay and throughput. This paper presents a performance comparison between real time and static download services based on QoS metrics (Media Access Delay, Queue Size and Delay). The performance comparison which is compiled using the OpNet simulator illustrates the importance of optional buffer configuration. The connection oriented design of MANET media access control results in significant increase of the delay regardless of the connectionless nature of the utilizing application. Results presented illustrate that suboptimal buffer configuration can render a real time streaming service unusable.**

Keywords - Ad-hoc Network (MANET), AODV, QoS

I. INTRODUCTION

Mobile Ad hoc Network (MANET) is a decentralized wireless network that does not rely on a pre-existing infrastructure, such as routers or access points. Each node participates in routing by forwarding data for other nodes. In such a configuration the determination of which nodes forward data is made dynamically based on an AODV routing algorithm. A MANET configuration is ideal in swarm like behavior, where nodes are tasked with a singular task and they need to delegate sub tasks between each other. In such scenario it is crucial that message is received with minimal delay.

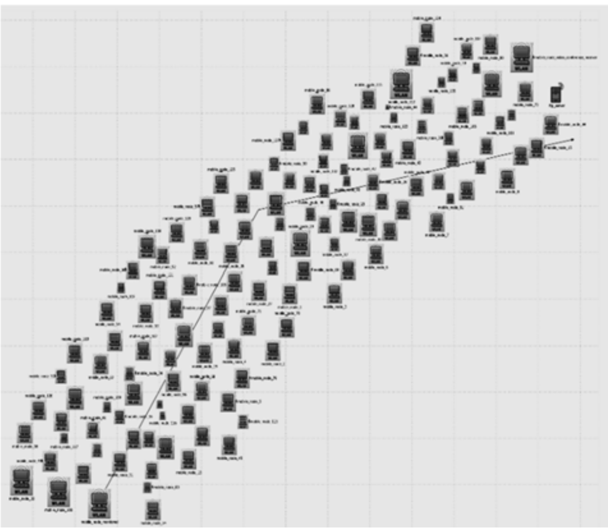

Figure 1. OpNet Simulation topology

In order to validate the MANET configuration and test the load under controlled condition, we used OpNet Modeler.

We created an OpNet simulation of 139 mobile stations (MS) as illustrated in (Fig 1).

The network topology uses the AD-HOC using an On-Demand Distance Vector (AODV) routing protocol. One station in the scenario is a moving station called "mobile-node-monitored". The moving station follows the path illustrated in Figure 2 for one hour.

Two scenarios are compared using light and heavy loads as illustrated in Table I. Both scenarios have the same number of stations, the moving station is moving in same path and speed. The scenarios differ in terms of transmit power, which was increased due to necessity as higher load required more transmit power. Without the power increase the communication degrades to the point when moving station loses connectivity.

A MANET network is entirely dynamic as no Master Node is required to manage the network. All the nodes collaborate collectively to maintain a robust link. This makes MANET networks much more resilient than MESH networks, and much less prone to failure. In the network where we rely on live data i.e. sensory data streams or video stream per node, minimal data loss and low latency is very important.

Issues arise when we have a dense network configuration. Interference over the medium will result in delays and packet corruption as described later in this paper. We will also focus on MAC Buffer size and its effect on latency and throughput.

The first two simulations will identify limitations of a dense MANET network under heavy load, a second set of simulations will highlight the MAC Buffer size importance.

The difference between Light and Heavy Load simulation is the frequency of FTP transfers (Table I). The FTP transfers

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are between FTP Server and "mobile-node-monitored" Node (Figure 2).

II. LITERATURE REVIEW

The concept of using IEEE 802.11 Ad-hoc networks in wireless Internet of Things (IoT) is widely implemented. According to 802.11-2012 - IEEE Standard for Information technology [1]. At minimum IEEE 802.11 LAN may consist of two stations (STA). No access point (AP) in form of router for example is needed. We focus on MANET in this paper because of its decentralized nature that means no central AP is needed which is aligned with our use-case. Relevant to this paper are performance studies focused on STA in MANET performing routing between STA in search of better performance [2]. A number of articles highlight performance issues including the "ping-pong" effect [3], Yield Based Collision [4], Multi-hop in Ad-hoc Network [5], and incorrect node selection for broadcasting message [6][7][8][9].

In all these studies the routing protocol played an important role. One of the attempt to combat the end-to-end delay is to cluster the STA to decrease the delay [16]. Through out of most referenced papers the network performance is decreased when STA count increases. That is known fact, and problem we are trying to address in this paper. In this paper we are using Ad hoc on demand Distance Vector Routing (AODV) [7][9][10] [11]. AODV is the default protocol and is commonly used in mesh networks. When running heavy load, the transmit power must be increased in order to avoid communication degradation and failure [12][13]. In some articles, Collision Avoidance and Protocol with Fast Retransmission Strategy [14] was applied. Other approaches used the Cluster Dynamic Slot Assignment Protocol [15].

This study is created to evaluate Ad-hoc network performance in dense environment such as a outdoor match. We can expect 30 000 to 100 000 visitors in event like that where each visitor may have at least one 802.11 capable wearable device, such as smart phone, or smart watch. The 802.11 network will be utilized in autonomous swarm like drone network to monitor such as event. Each 802.11 device will be sharing common transmission medium, therefore delays will be introduced.

Closest attempt to address network delay and throughput in such scenario is by implementing caching mechanism [17]. This study is evaluating scenario with 35 nodes, which is not representing our use case. As it is seen in this paper, we are running scenario with 139 nodes. Simulation time with 139 nodes was 17 hours, therefore we decided not to increase the node count but set each node according to Table I.

III. SIMULATION CONFIGURATION

This section outlines the test configuration which was implemented using the OpNet simulator. The configuration consisted of 139 mobile stations as illustrated in Figure 2. The network topology uses the AD-HOC routing protocol. One station in the scenario is a moving station called "mobile-node-monitored". The moving station follows the path illustrated in Figure 2 for one hour.

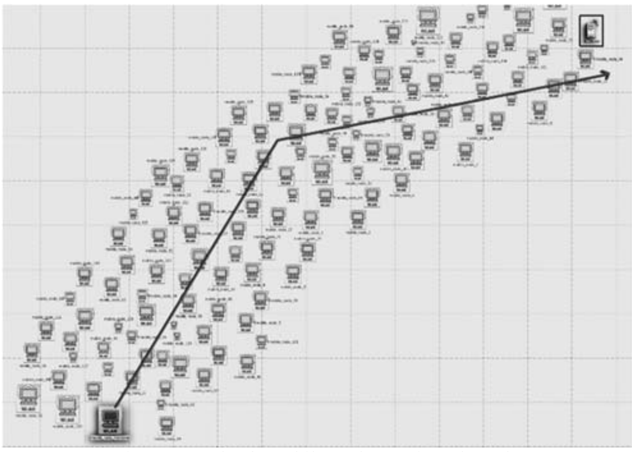

Figure 2. Path of "mobile-node-monitored" node

Table I illustrates the configuration used in the simulations.

TABLE I. SCENARIOS CONFIGURATION

Light		Heavy	
AD-HOC	AODV	AD-HOC	AODV
Physical Layer	HT PHY 5GHz (802.11n)	Physical Layer	HT PHY 5GHz (802.11n)
Data Rate (Mbps)	65 (base) / 600 (max)	Data Rate (Mbps)	65 (base) / 600 (max)
Number of Spatial Streams	4	Number of Spatial Streams	4
Transmit Power (W)	0.6	Transmit Power (W)	1.3
FTP		FTP	
Get/Total Mix	75%	Get/Total Mix	75%
Inter Request Time	2 Seconds	Inter Request Time	0.5 Seconds
File Size	500KB	File Size	500KB
Type of Service	Best Effort (0)	Type of Service	Excellent Effort (96)

Metrics for performance evaluation were:

- Delay (sec)
- Media Access Delay (sec)
- Queue Size (packets)
- Throughput (bits/sec)

A. Delay (sec)

Represents the end-to-end delay of all the data packets that are successfully received by the WLAN MAC and forwarded to the higher layer.

B. Media Access Delay (sec)

The total of queuing and contention delays of the data, management, delayed Block-ACK and Block-ACK Request frames transmitted by the WLAN MAC. It may also include multiple number of backoff periods, if the frame is delayed due to one or more internal collisions.

C. Queue Size (packets)

Represents the total number packets in MAC's transmission queue(s).

D. Throughput (bits/sec)

Total data traffic in bits/sec successfully received and forwarded to the higher layer by the WLAN MAC.

IV. PERFORMANCE METRICS

A. End-to-end Delay (sec)

$$eed = \frac{1}{n}\sum_{n=1}^{n}(rt_n - ts_n)$$

End-to-end delay (eed) is determined by subtracting time at which data packet n was sent (ts) from time at which data packet n was received (tr). The eed delay is in seconds, and lower eed is better. The performance is directly related to queue size and media access delay.

B. Throughput (Kbits per second)

$$thp = \frac{\sum pr}{ts}$$

Throughput (thp) is the total packets successfully received (pr) over the time in seconds (ts). Higher throughput is better.

V. SIMULATION RESULTS

Figure 3 illustrates the simulation scenario and the trajectory of monitored node form which we collected the results. The simulation was 60 minutes in duration. Each node transfers 500KB (Table I) files with an FTP server. The FTP server is located top right corner of the scenario.

Based on Figure 3, we can see that delay in second is in between 21 to 24 seconds indicating extremely poor performance. The ideal delay should be in milliseconds, below 1 second.

The Media Access Delay is related to Delay in seconds (Figure 3). Where the Delay is time between packet sent and packet received. The media access delay start counting time from packet being added to transmittion queue. The counding ends when the packet is received in destination physical layer.

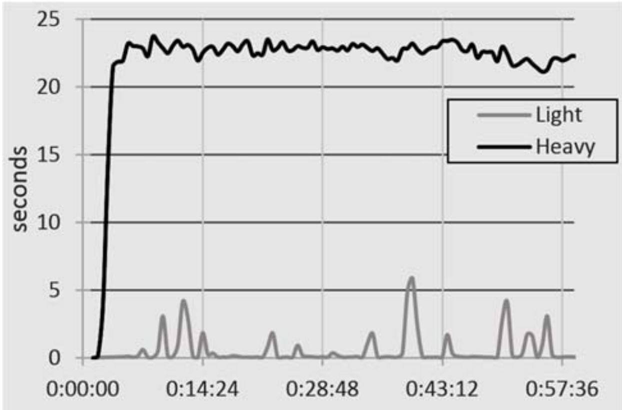

Figure 3. Delay in seconds

The delay sums up when traversing between nodes. The Figure 4 is ilustrating that. From 44 min of simulation time of heavy use, the Media Access Delay is decreasing. That is because the node is closer to the FTP server node.

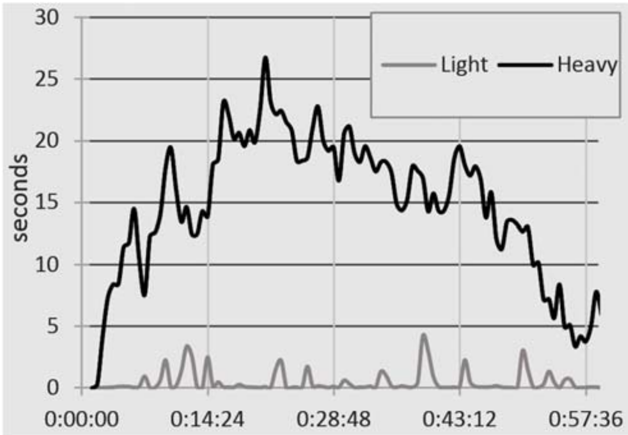

Figure 4. Media Access Delay in seconds

Queue size is number of packets in transmission queue. In Figure 5 we are observing the queue size of moving node from Figure 2.

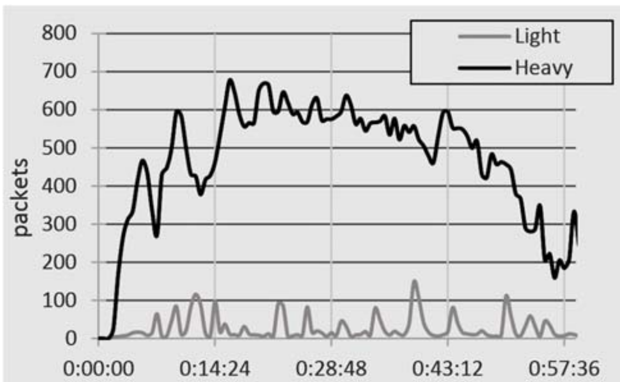

Figure 5. Queue Size in packets

We can see that it closely relates to Media Access Delay. The queue size is peaking at 700 packets just in 15 minutes of the simulation. After 43th minute in simulation the queue is dropping. That because moving node is closer to the FTP server.

During heavy load, the throughput is at 150Kbits/s, +/-50Kbits (Figure 6). Which is very bad and not great for data streaming. The light load shows higher throughput averaging in-between 1000Kbits to 1500Kbits or 1MB to 1.5MB.

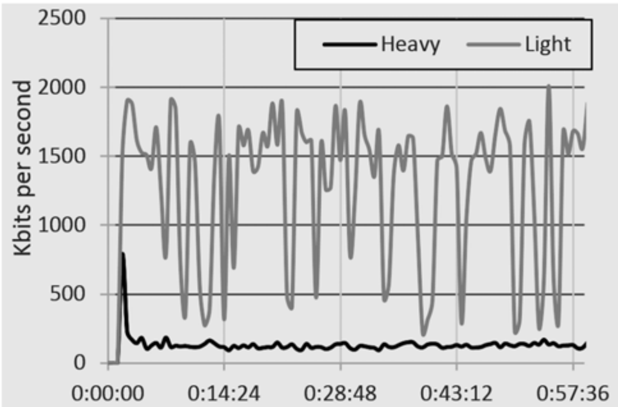

Figure 6. Throughput in Kbits per second

Based on simulation results we can see high impact on the Quality of Service (QoS). The data transmission medium is air, not point-to-point medium such as copper wire or optic wire. Therefore, each node in close proximity shares the medium, and only one transmission at the same band and channel can be made at the time. The Media Access Delay and Queue Size metric clearly visualize that case. Once the moving node is closer to the FTP server (Figure 2) the Media Access Delay and Queue Size drops.

VI. HIGH DELAY SOLUTION

The Delay in dense MANET network under Heavy Load will affect QoS. From Figure 3 we can see delay of 20 to 25 seconds under Heavy Load. Such high Delay is not acceptable when we are dealing with live data and mobile nodes.

Considering current conditions and scenario we are in, solution to decrease the Delay can be achieved by altering Buffer Size in wireless adapter of each node.

Buffer Size (bits)

- Specifies the maximum size of the higher layer data buffer in bits
- Once the buffer limit is reached, the data packets arrived from higher layer will be discarded until some packets are removed from the buffer so that the buffer has some free space to store these new packets

Focus of this experiment is on Heavy Load Scenario. The Heavy Load scenario was duplicated and the Buffer Size in bits was changed according to Table II.

TABLE II. BUFFER SIZE CONFIGURATION

	Buffer Size (bits)	
	Default	***Altered Buffer***
Heavy Load Scenario	256 000	64 000

We are comparing same metrics as before:

- Delay (sec)
- Media Access Delay (sec)
- Queue Size (packets)
- Throughput (bits/sec)

As mentioned, we are altering Heavy Load scenario. All parameters are same excluding the Buffer Size. That means the frequency of file send by all nodes is still same, but we can see major improvement in the Delay. We managed to drop the delay from 20 to 25 seconds to 5 to 6 seconds, Figure 7.

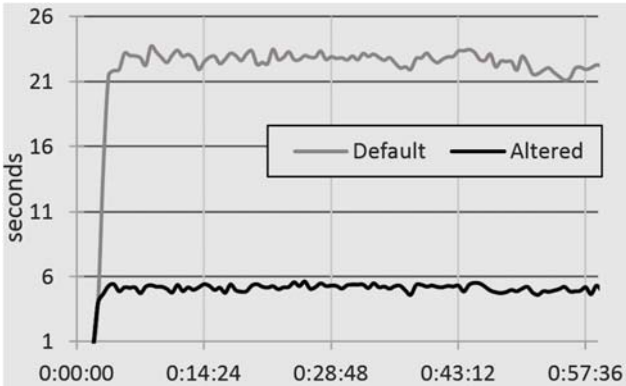

Figure 7. Delay in seconds with altered Buffer

Same pattern continues with the Media Access Delay. We can find that in very consistent average the access delay is ÷4 seconds comparing to highest of 25 seconds in Heavy scenarion without buffer alteration. That is in its own right great improvement, Figure 8.

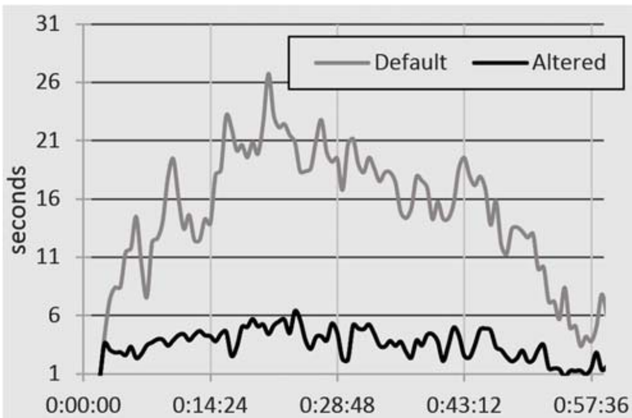

Figure 1. Media Access Delay in seconds with altered Buffer

Trend continues with Queue Size. The highest max is 120 packets (Figure 9), which is almost same as with Light Load without buffer alteration.

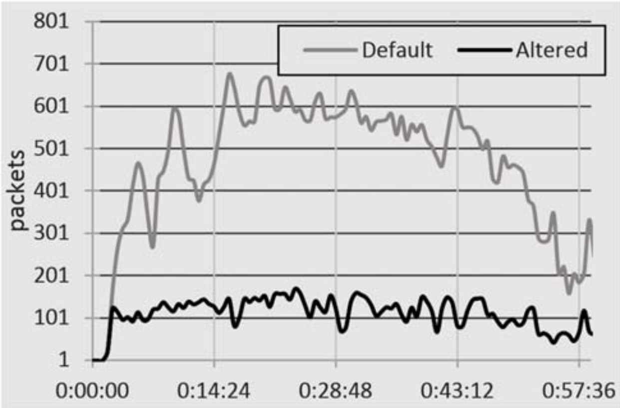

Figure 9. Queue Size in packets with altered Buffer

Now with the buffer altered and Delay reduced, question is if the QoS is still acceptable. To answer the QoS question, let's have look on the Throughput and the Data Drop resulted by altered buffer, Table II.

Altered buffer have no significant effect on Throughput. The simulation results (Figure 10) is showing that the throughput is not affected. It is not improved comparing with Light Load throughput, Figure 6.

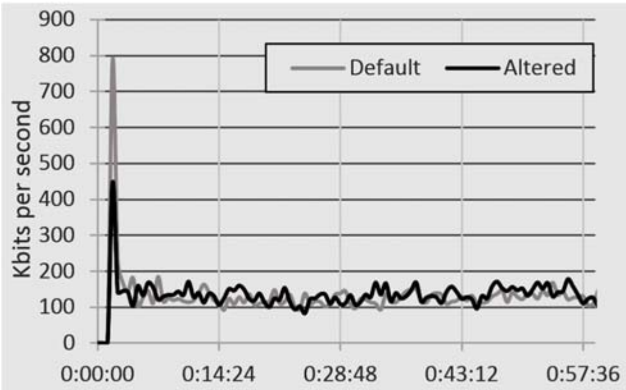

Figure 10. Throughput in bits per seconds with Altered Buffer

Last metric we are going to look at is the Data Drop, which can be directly related to Buffer size. We collected the Buffer Overflow and Retry Threshold Exceeded metrics.

A. Data Dropped (Buffer Overflow) (bits/sec)

Higher layer data traffic dropped (in bits/sec) by the WLAN MAC due to:

- full higher layer data buffer
- the size of the higher layer packet, which is greater than the maximum allowed data size

B. Data Dropped (Retry Threshold Exceeded) (bits/sec)

Higher layer data traffic (in bits/sec) dropped by the WLAN MAC due to consistently failing retransmissions. This metric reports the number of the higher layer packets that are dropped because the MAC couldn't receive any ACKs for the (re)transmissions of those packets.

Sending and receiving 500kb files every 0.5 second (Table I) is not significantly affected by reducing the Buffer. From Figure 11 we can see that the Buffer overflow is similar if not lower in some points with smaller buffer size. This alone is justifying the action of reducing the buffer in dense MANET Network with intention to reduce Delay in the network.

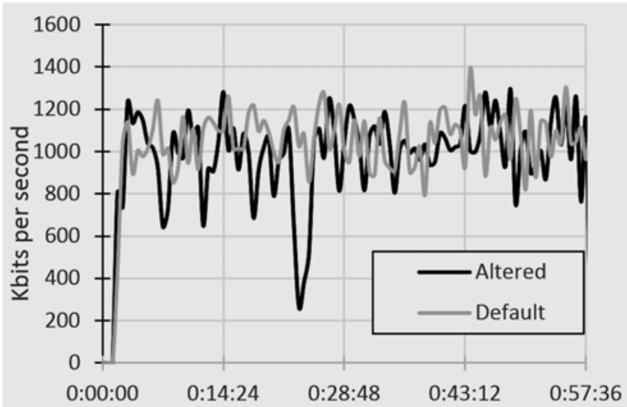

Figure 11. Buffer Overflow in bits per second

Looking at Retry Threshold Exceeded metric, Figure 12, we can see spikes, and they are significant, they are related to node trajectory and packet switching/routing. It should be subject for use-case evaluation, and further research. Excluding the spikes, the trend is like simulation without buffer alteration.

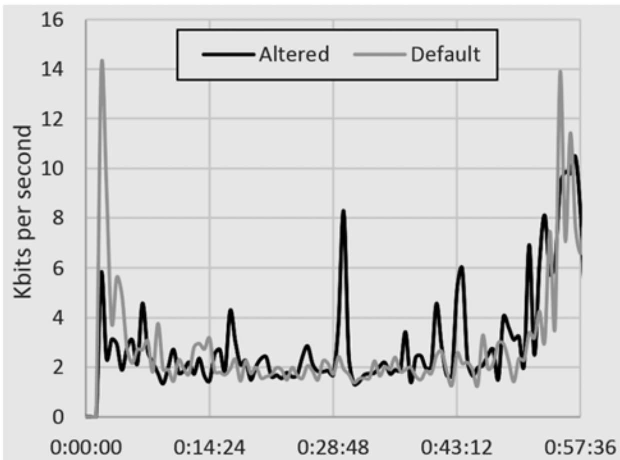

Figure 12. Retry Threshold Exceeded in bits per second

VII. CONCLUSIONS AND FUTURE WORK

This paper proposed further evaluation and optimization of the MAC Buffer size. The goal of the optimization is to increase performance of 802.11 network in dense environment such as a live sporting event. We can expect 30

000 to 100 000 visitors in such event. Sisco predicts over 70 percent of the global population will have mobile connectivity by 2023 [18]. Considering that we can expect thousands 802.11 enabled devices at such event, which will affect overall network performance. By altering MAC Buffer size, we achieved latency reduction and increase of performance. The buffer alteration was done under heavy load scenario according to Table 1. The heavy load scenario demonstrated very high delays which will render the service unusable (Figure 3,4,5). Figure 7 is visualizing the improvement with altered buffer. Bearing in mind that Default and Altered results are under Heavy Load (Table 1), we can clearly see the performance increase. Altered Buffer under Heavy Load is in same range as Default scenario with Light Load.

The simulation was conducted using OpNet Modeler. Two scenarios were set as a Mobile Ad-hoc Network. In each scenario simulation we have 139 nodes and one ftp server. They are configured according to Table 1 The node from which we collect metrics, is traversing through scenario on predefined trajectory (Figure 2). We can observe the latency drop in the end of the simulation. That is due to reduced distance between monitored node and the FTP server. In Heavy Load simulation, we are experiencing Delay up to 24 seconds, which would render use case to not suitable. The results have clearly highlighted that the delay is caused by high Media Access Delay and related high package Queue. The limited medium availability which is air also affected the overall Throughput.

Once the limitation was identified, a possible solution was introduced. Giving available tools in the simulation, Buffer size a wireless LAN parameter was adjusted according to Table 2. This alteration successfully reduced the delay by 5 times. From 25 seconds to 5.5 seconds. Throughput was not improved, but it was expected. The load was not changed.

Finally, the solution was validated with Data Dropped metrics. The Buffer Overflow did not exceed the base results (Figure 11), in fact it dipped significantly in some cases, which was surprising. Expected outcome was higher data drop. Comparing the Delay between default buffer and altered buffer (Figure 7) and cross referencing with Buffer Overflow Data Loss (Figure 11) shows great potential in optimization buffer size for ideal results.

On other side, the Threshold has exceeded the base results in some cases (Figure 12), we recorded major spikes comparing to base readings. This can be result of failing retransmissions. That means if buffer is smaller the threshold is reached faster. Which also lead to buffer size optimization. Another factor which is affecting the Retry Threshold Exceeded is the routing or packet switching. The AODV protocol can be optimized or evaluated for this use case [9][11][12]. Efficient path selection in Ad-hoc network is important for packets transmission between sender and receiver.

Smaller buffer clearly indicates better latency (smaller delay), but as seen the threshold is exceeded faster. Considering the buffer alteration, we did not record any major data loss with altered buffer.

All considered, decreasing the buffer size and forcing quicker transmissions of smaller packet chunks yields better performance. Our use case depends on minimal delays between nodes. We are setting a stage for autonomous network, where updates will be important. Nodes will be mobile, they will be reporting their position for collision detection and avoidance for example. The message delay can cause a collision or out of place position. The specific use case makes this study unique, because the main initial focus is on latency. we are not expecting large Frames, therefore buffer size impact validation is correct choice for this paper.

Also optimization of the AODV protocol implementation can contribute to better QoS. We are dealing with Ad-Hoc network, and some of troublesome are the packet path planning, number of packet hops limits and resulting retransmissions.

Future Work: The negative spikes in Threshold Exceeded Data Loss (Figure 12) along with positive results in Buffer Overflow Data Loss (Figure 11) will be focus in following paper. Optimization of Buffer Size in the Wireless Adapter has positive impact in reducing latency in the Ad-hoc Network.

Once ideal Buffer size is defined, the AODV routing protocol will be optimized to further reduce latency without sacrificing throughput. The Retry Threshold Exceeded is expected be same or lover than base.

Following paper will be focused on optimal Buffer Size in Wireless Adapter along with optimization of the AODV routing protocol. Use case will be multiple mobile nodes, in dense Ad-hoc Network (MANET) with high traffic among each node. By dense we understand multiple nodes in proximity spanned in area of 1 km^2.

Also as mentioned in conclusions, focus for next papers is use case of real-time data transfers in Ad-hoc Network with optimized Buffer Size and AODV routing protocol.

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