

## Emergency Prenatal Telemonitoring System in Wireless Mesh Network

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### Abstract

*Telemedicine promises a great opportunity for health care service improvement. However, it has several issues for its implementation in certain area. They include communication service quality, infrastructure and operational cost. Since Wireless Mesh Network (WMN) is designed to reduce the infrastructure cost and operational cost, an investigation of network performance for implementation of telemedicine is required. In this paper, a simulation to investigate the wireless mesh network quality of service. Using network simulator 2, The QoS performance analysis was performed in different routing protocol scenarios of proposed system. It showed that OLSR protocol for Mesh Network maintained the time transfer of the EPT data. The field testing of the proposed system to measure the distance with various time has already been done. The infrastructure has been also implemented using low cost 5.8 GHz transceiver for backhauls and low cost 2.4 GHz transceiver for clients. Test result shows that the low cost telemedicine system is able to do real time communication between patient and medical staff with medical data rate up to 2 Mbps. It shows that telemonitoring system using wireless mesh network can give a low cost application in emergency time with acceptable medical data transfer quality.*

**Keywords:** Telemedicine, Telemonitoring, Wireless Mesh Network

### 1. Introduction

Wireless communication technology has seen the fastest growth in the history to provide telemedicine innovation, boosted by deployment of enabling technology and technological advanced in signal processing, access and coverage area. The well established and emerging wireless technologies have tackled the location boundary from wired based telemedicine, where the parties need at specific place with the cable connection. The parties involved can tap into vital information anywhere and at any time within the wireless network coverage. Various wireless telemedicine solutions have been proposed and developed by adopting recent wireless technologies.

Most proposed solutions were based on commercial off-the-shelf wireless technologies, with enhancements on flexibility and deliverability on heterogonous data. The use of commercial network services, such as cellular and long term evolution (LTE), creates problems in integration between different global communication options and standards. Restricted scalability of the network provider may also limit the extent of telemedicine service especially in the low market area. The reliability and the quality of medical data exchanges in this network are very much reliant on the service level from network provider. The use of independent wireless network is needed to provide an open integrity for telemedicine service enhancement.

Various wireless technology solutions have been proposed and deployed in telemedicine application. Most proposed solutions are based on off-the-shelf and established wireless technology, with enhancements for flexibility and heterogonous service delivery. Wireless technology also provides reliability, flexibility and portability from telemedicine service requirement. These wireless and wired technologies infrastructures for telemedicine services are summarized in Table 1.

Table 1. Comparison of available network infrastructure/technologies for telemedicine system

infrastructure/technology	bit rate (Mbps)	investment cost*	operational cost	user device cost	mobility
Fiber Optics	2,550,000	H	M	VH	No
ATM	155	VH	H	VH	No
ADSL	8	H	M	M	No
ISDN	0.128	H	M	M	No
VSAT	4.09	VH	M	VH	No
GPRS	0.115	H	L	L	Yes
EDGE	0.256	H	L	L	Yes
3G UMTS	0.512	H	M	M	Yes
HSDPA	3.6	VH	M	M	Yes
WMN	54	L	VL	L	Yes
WiMAX	54	M	VL	L	Yes

Note:

$$* \text{ investment cost} = \frac{\text{cost of investment}}{\text{number of user node that can be serviced}}$$

VH = very high, H=high, M=medium, L=low, VL=very low

Each infrastructure has its own obstacle, particularly when they are implemented in the area where connectivity is the main issue. In the wired based infrastructure, Asynchronous Transfer Mode (ATM) and Multi Protocol Label Switching (MPLS) as a telemedicine backhaul, have limitation in mobility and scalability, even though both networks support Quality of Service (QoS) and have stability on delivering data [1].

The preliminary review of wireless application for telemedicine has been done in Pattichis *et al.* [2] by classifying technology into WLAN, global system for mobile communication (GSM) as cellular technology and satellite. Review in Ng *et al.* [3] has broaden the use of short-range wireless in sensor technology and birth of WiMAX to be used in telemedicine. Progress in cellular technology has initialized the wireless application on cellular technology into mobile-health (m-Health) by Istepanian *et al.* [4] and classified them into 2G and beyond 3G m-Health application. Although definition of m-Health in Istepanian *et al.* [4] and Micheli-Tzanakou *et al.* [5] incorporates all types of wireless, almost all scientific paper in m-Health domain focused on proprietary cellular technology. The fragility of 3G UMTS network for telemedicine where the implementation costs are high and does not support QoS has been explored by Tan *et al.* [6].

The main general focus of this research is to provide a good telemedicine services at distance and with low cost implementation on single/multi-user and inter-communication domain. The use of commercial network services, for example cellular and LTE, creates problem in integration between different global mobile communication options and standards. It also resulting difficulties in m-health compatibility linkage between operators and network providers. Restricted scalability and proprietary technologies for cellular and LTE may also limit the expansion of the network in underserved areas. Satellite technology could provide the most wide coverage than other wireless technology, but the high-cost of communication link per used creates the drawback on implementing satellite in telemedicine area [7, 8].

The proliferation of low cost wireless mesh network (WMN) in a number of large scale implementation, e.g. MIT roofnet [9], has opened the door for independent telemedicine infrastructure. The Institute of Electrical and Electronics Engineers (IEEE) provides the work of emerging IEEE 802.11s standard for semi-infrastructure of wireless mesh network. The IEEE 802.11s has a self-organization characteristic, scalability in coverage area and its carrier technology solely based on independent and free license-exempt frequency spectrum. The 802.11s gives less backhaul connection to every wireless node in the network compared to the conventional wireless local area network (WLAN) deployment. It is a low cost network with the reduction of installation, commissioning and operational cost thereby achieving 70% saving compared to conventional approaches [10]. These criteria offer promises for the open implementation of cost-effective telemedicine services. IEEE 802.11s is suitable candidate to leverage telemedicine service with the lower cost technology.

Even though the promises of implementing wireless mesh network as telemedicine infrastructure are feasible, study shows only one large scale telemedicine project had been done within past ten years. This project was launched in 2007, called Emergency Room Link

(ER-LINK) worked on 365 square kilometer with 95% coverage area of the city of Tucson, Arizona, USA [11]. Unfortunately, due to its lack of operational fund, this project had been shut down since 2011 by the local government albeit the mesh infrastructure still in use daily [12]. This project involves the use of Open Link State Routing (OLSR) WMN type.

The other telemedicine infrastructure involving non-802.11s standard of WMN could be seen in Pirzada *et al.* [13] for the incident area infrastructure, the work from Yarali *et al.* [14] for the emergency application and triage infrastructure by Marti *et al.* [15]. However, most of the work performances, in terms of throughput and delay, degrade significantly as the source is located at an increasing number of hops away from the destination.

## 2. Scenario

The scenario for low cost telemedicine system is based on our developed devices and infrastructure. The detailed of the development and its system could be seen in [16-18]. The general description is depicted in Figure 1, involved remote patients and health-care services that are equipped with medical data assistant (MDA). The MDA acquires the medical data using Medical Device Interface (MDI). MDI retrieves medical data from various medical devices.

Currently, the developed interface function to medical device has been done for electrocardiography machine (ECG), Doppler instrument, blood pressure monitor, ultrasound machine and stethoscope. The MDA are connected through wireless router and transceiver for data transmitting between patient and doctor. Two-way communication between patient and doctors is supported by camera and microphone. All of patient medical data are continuously recorded inside the server for diagnostic purposes.

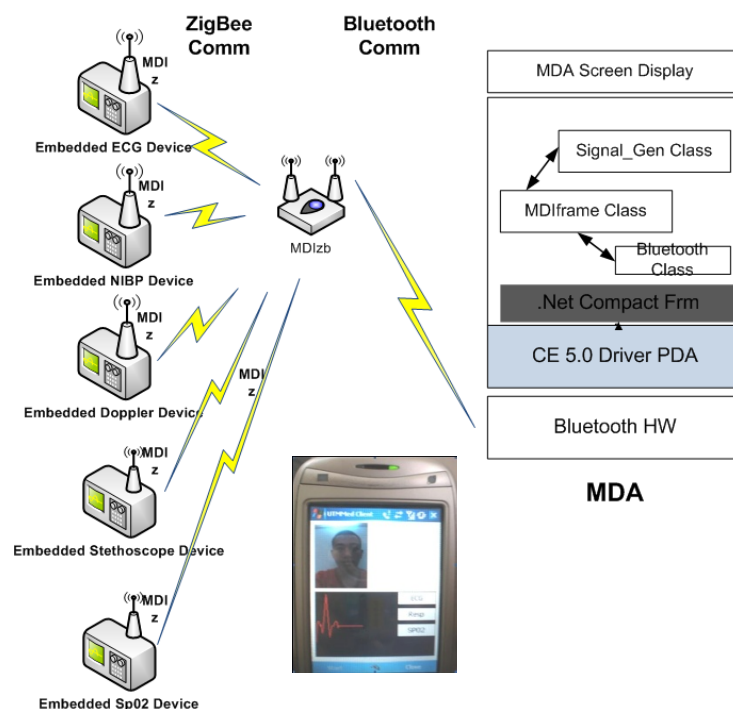


Figure 1. Device configuration of low cost telemedicine infrastructure

The result of average data rate measurement for seven medical devices from MDA system is listed in Table 2. Good means the medical data is encoded, while excellent means data is not encoded. In simulation, the data of medical devices were transmitted and received between patient and hospital via multi-hop backhaul. The total of good and excellent data rate depict the required data rate for single MDA system. As we can see the average data rate required from a single MDA system is similar with the selected data type traffic in Table .

Table 2. Result of Average output data rate [16]

devices	data rates	
	good	excellent
ECG	15 kbps	89 kbps
Doppler Instrument	40 kbps	160 kbps
Blood Pressure Monitor	1 kbps	2.4 kbps
Ultrasound Machine (Image)	104.6 kbps	400 kbps
Camera	136 kbps	2,020 kbps
Digital Stethoscope	40 kbps	160 kbps
Microphone	22.2 kbps	160 kbps
Total	358.8 kbps	2,991.4 kbps

### Mesh Point as backhaul

The field testing has been done to investigate the network performance between remote patient MDA and the reliability of system. The network performance including signal quality of outdoor infrastructure, the outdoor maximum data rate that can be achieved and the MDI capacity has been tested. The reliability system also has been tested especially against the interference and weather changing in long time duration.

Parameters for the WMN outdoor backhaul are described in Table . The operational frequency of 5.750 GHz has been used to overcome distance and obstacles between backhaul connections.

The measurement is done for 7 days at 3 WMN backhaul using The Dude network monitor from Mikrotik™. As in Figure 2, the snapshot of the running monitoring measurement with sampling rate 1 second. The performance testing result shown in Table 11 is the average value for each low cost telemedicine backhaul at 1.2 km distance. The result shows the noise rate varies from its receiver sensitivity. The average signals for each backhaul in open space area with clear weather are in range -26 - -28 dBm. This gives the SNR values of 72 dB for low SNR and 82 dB for high SNR.

Table 3. Technical specification of WMN Backhaul

parameter	value
antenna	
type	directional antenna
gain transmitter	1 dB
gain receiver	1 dB
receiver sensitivity	-100 dBm
network interface	
input power (max)	1 W
channel frequency	5.750 GHz
data rate	54 Mbps
Router	
Brand	RouterBOARD 333
Interface Card	W-miniPCI card 100 Mw
Antenna Connector	Low loss cable LM58

Table 4. Performance testing of each backhaul at 1.2 km

Location	antenna	band (MHz)	noise high (dBm)	noise low (dBm)	signal strength (dBm)
Location 1	1	5180	-98	-106	-26
	2	5180	-98	-107	-28
Location 2	3	5180	-98	-108	-26
	4	5180	-97	-108	-28
Location 3	5	5180	-98	-106	-26
	6	5180	-98	-106	-26

Table 5 shows the average values from connection measurement in each number of hops. Hop is counted from the user in location 1 to the destination in other location. The data rate was calculated from the average of data rate of each user. Testing results shows that the low cost telemedicine infrastructure within 3 hops on 3.4 km distance could fulfill the requirement of medical data rate of more than 2.8 Mbps for excellent quality of medical data. Moreover, the attenuation of weather and obstacles, such as building and tree) has decreased the SNR value into low than 72 dB in distance of 1.2 km. High data rate has also gave the impact on the attenuation of the signals, which could give the impact on the SNR value.

Table 5. Connection characteristic per hop between backhaul

Hop Count	Avg. Distance (km)	Avg. SNR (dB)	Avg. Throughput (Mbps)
1	1.2	54	6.35
2	2.6	32.5	4.62
3	3.4	30	4.11

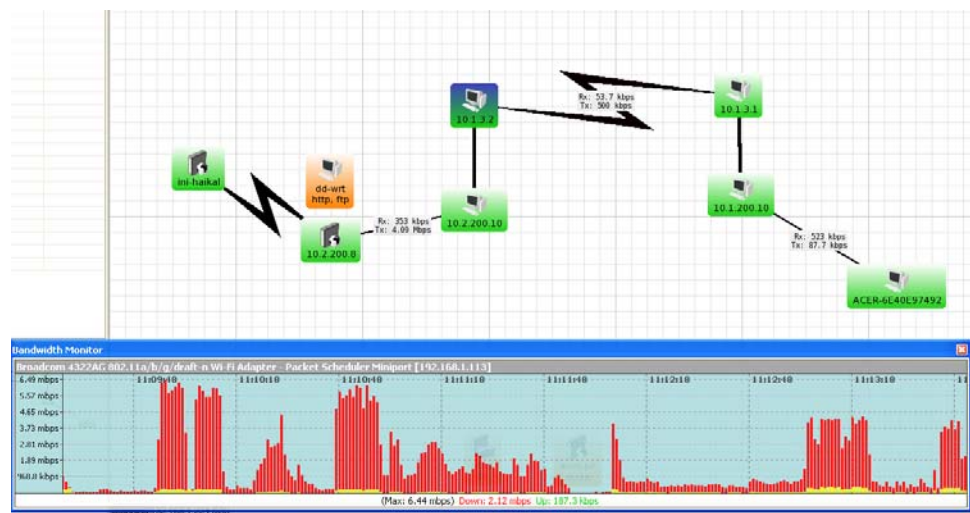


Figure 2. Snapshot of WMN backhaul measurement

### 3. Performance Analysis

The objective of this paper is to provide Wireless Mesh Network as the backhaul for remote patients in distance from healthcare personnel. This means the longer-range transmission is required with the high data rate support. As describes in Chapter 2, the communication between MP that are out of the transmission range is done by using intermediate MP. Hence, the communication among these MPs could be done if each MP holds the information of the destination route through intermediate mp.

The limitation of the available testing device for MDA and the backhaul are the main factor to analyze this routing characteristic. Here, the utilization of ns3 simulation framework is selected as the best way to measure the impact of different routing protocols in wireless mesh network.

In this section, we analyze the performance of AODV, OLSR and 802.11s HWMP routing protocol. HWMP is the layer 2 routing and its reactive mechanism is based on layer 3 AODV routing. OLSR represents the proactive routing for WMN, where nodes periodically exchange routing tables and maintain the entire topology of the network. Both OLSR and AODV are using the traditional hop count as routing metrics and does not include any link quality sensing. The main question need to be answer in this analysis are whether the 802.11s WMN are the best as the backhaul telemedicine among the other routing mechanism. Second mandatory question is the impact of routing metrics in layer 2 and layer 3 for the WMN network.

Four performance parameters were evaluated in this simulation. They are (1) end-to-end delay, (2) throughput, (3) jitter and (4) the percentage of packets loss at the receiver node.

It is difficult to directly measure the end to end delay, due to the unsynchronized nature of multi hop WMN. We estimate the end to end delay by the round trip time delay i.e., the delay from the source to the destination and back to the source. End to end delay in this simulation is given by:

$$D = \frac{\sum_{p=0}^n D_{end} - D_{start}}{n}$$

where:

$T$  = End to end delay (ms).  
 $T_{end}$  = Time of packet received (ms).  
 $T_{start}$  = Time of packet sent (ms).

The throughput ( $\lambda$ ) value is measured from packet arrival rate  $\lambda$  at the mesh clients. The packet average end to end delay has to remain finite. Equation of throughput (T) for WMN is given by:

$$T = \frac{P(n)}{D}$$

$T$  = Throughput (Kbps)  
 $P(n)$  = Number of packet (Kb)  
 $D$  = End to end delay (s)

The packet loss parameter is measured by the percentage of the number of loss data packets sent by receiver to the destination.

$$PLR = \frac{fsDrops}{numFs} \times 100\%$$

where:

$PLR$  = Packet loss ratio (%)  
 $fsDrops$  = Number of packets drop  
 $numFs$  = Number of packets sent

Analysis of simulation results were evaluated for the system describes in section 4.3 in wireless mesh network based on four QoS parameters.

### Experimentation Parameters

The simulation physical environment in table 6 describes the technical specification of WMN backhaul. A path loss model is based on Kun path Loss model [19] for wideband channel. The common path loss for open space model, such as Okumura-Hata, has coverage not more than 1.5GHz. The path loss model at 2.6GHz per distance is stated as:

$$PL(d) = 43 + 26 \log_{10} d$$

This empirical model is a typical outdoor suburban and urban environment with uniform distance more than 1km and carrier frequency higher than 2.3GHz. The path loss exponent is 2.2 with a standard deviation of 9.3dB.

Performance comparison between routing protocols available for WMN is done for AODV,OLSR and HWMP at 802.11g. The use of Droptail queue type assumes that packet of MDA data would be dropped by First in First Out (FIFO) scheme when the buffer is more than 100 packets.

Table 6. Simulation parameters of General environment model

	Parameter	Values	
Channel Model	Propagation Delay	Constant Speed	
	Propagation Lost	Kun Path Loss Model	
	Carrier Frequency	2.4	GHz
	System Loss Coefficient	1	
Mesh Device Model	Reception Gain	1	dB
	Transmission Gain	1	dB
	Transmission Power	25	dBm
	Reception Noise Figure	7	dB
	CCA Threshold	-62	dBm
Data Link Model	Energy Detection Threshold	-96	dBm
	Modulation Scheme	OFDM	
	Fragmentation Threshold	2346	byte
	MAC Packet Length	1500	byte
	Slot duration	20	us
	Number Slots per Frame	100	slots
	Max Queue Size	100	Packets
	MP Distance	1	Km
Routing Protocol	HWMP, AODV and OLSR		
Application	Packet Size	1024	Bytes
Packet Rate	Packet Rate	250	KBps

### Link Transmission Rate

The data transmission rate for this experiment is determined by combining the modulation and encoding scheme. This research compares each modulation and encoding parameters to determine the data link model. The extended rate physical OFDM modulation scheme is then selected to provide the higher throughput with the longer distance traffic carrier for WMN. In this section, we only provide the impact of modulation-encoding scheme of 802.11g-ERPOFDM as shown in Figure 3.

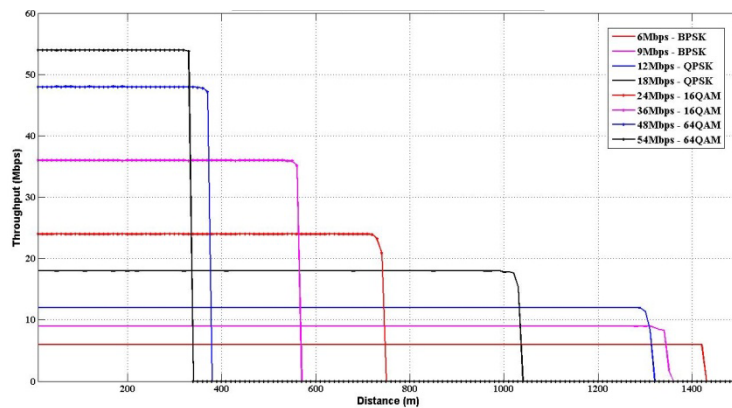


Figure 3. Comparison of 802.11s-ERPOFDM transmission rates against distance

### Hop Count

The comparison of the hop number for selected encoding could be seen in figure 5.7, where a single flow from source to destination MP is used. The mp distance in this experiment is set at 1km to minimize the hidden node effect between adjacent MP. The number of hops in here is defined as the number of mp needed for forwarding the transmitted the data packet from mp source to the designated mp. The supported encoding rate for long-distance are then selected as 6 Mbps, 18 Mbps and 24 Mbps. In figure 4.6, the effects of half-duplex nature against packet forwarding through the hop could be seen as the declining of the available throughput and increasing in end-to-end error rate. The variation trend of end-to-end delay results are the effect of establishing the route discovery mechanism in single available hop.



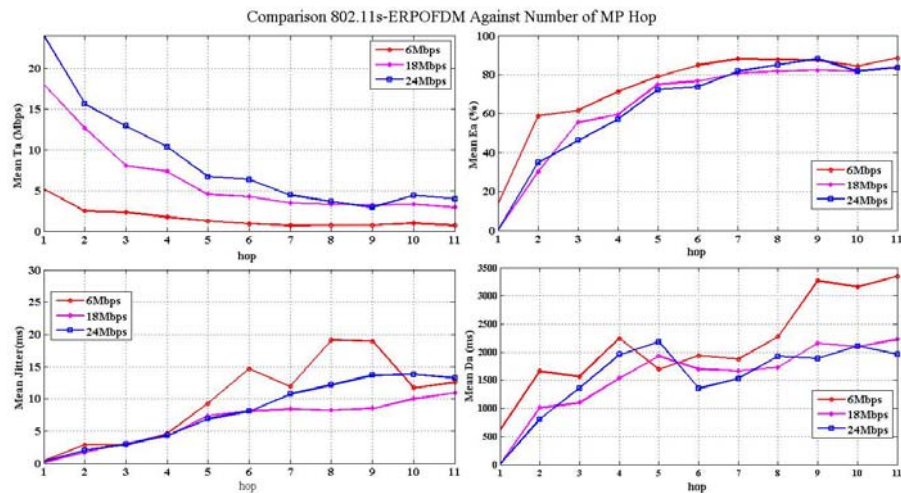


Figure 4. Comparison of 802.11s-OFDM transmission rates against number of MP hop

### Routing Model

Each routing protocol had to be configured using the similar parameter value by taking into account their differences. This parameter adjustment assures the comparison between them is fair and their differences are come from the routing mechanism. Several individual tests for routing has been done and the selected parameters result are shown in Table 7.

Table 7 : Protocol Specific Parameters

Parameter		Values	
802.11s Peer Link Model	Retry Timeout	5.09	ms
	Holding Timeout	5.09	ms
	Confirm Timeout	5.09	ms
	Maximum Retries	4	
	Maximum Beacon Loss	5	
	Maximum Packet Failure	2	
	Maximum Number of Links	2	links
802.11s HWMP Routing	Maximum PREQ Retries	3	
	Path active lifetime	2120	ms
	Root Active lifetime	2120	ms
	Interval PREQ	3048	ms
	Interval PERR	3120	ms
	DO Flag	1	
	RR Flag	0	
AODV Routing	Maximum PREQ receivers	6	
	Maximum Broadcast receivers	1	
	HELLO interval	1000	ms
	Maximum RREQ retransmissions	2	
	Maximum RREQ per second	10	
	Maximum RERR per second	10	
	Route timeout	11.19	s
OLSR Model	Maximum HELLO loss	2	
	HELLO interval	2000	ms
	TC emission interval	6600	ms
	MID emission interval	6600	ms
	HNA emission interval	6600	ms
Willingness		HIGH	

In this simulation, the transmission distance for each MP is set to the possible maximum of 1km. This makes the hidden MP effect and collision mitigation is unsuitable. Therefore, the HWMP maximum broadcast receiver, maximum number of links and maximum retry are reduced significantly from their default values. The timeout values for peer link model are increased because of the time needed to convergence a distance link is linearly increased with



the distance between peer MP. The changes on default DO and RR Flag are to overcome the flooding of control message effect and to make sure that the measurements is come from the data traffic from source and destination. By the same reason, the OLSR routing message emission interval and all control message lifetime in HWMP and AODV are increased.

All the loss parameters in each routing protocol are needed to be increased, especially in control message losses of HWMP and maximum hello loss of AODV. Their default values are extremely low for the long distance with exponential propagation loss. , The Willingness of OLSR is set to its highest value as there is no mobility aspect and MP is always act as intermediate MP.

### Scalability Analysis

The scalability of protocol is analyzed by utilizing grid topology as describes in Figure 4.7. Three grid models are evaluated for 3 x 3 (9 MPs), 4 x 4 (16 MPs) and 5 x 4 (25 MPs) with 1 kilometers of separation between MPs. This will guarantee that the path discovery could only be initialized by the closes intermediate MPs.

The numbers of data flows are established randomly between the nodes by scale of number MPs – 1. This will ensure the fairness of flow analysis for each protocol with durations per flow are exponentially seed in 50 seconds mean. The simulation is done in 800 seconds for each data rate sampling in a protocols. The packet size of each flow is set to 1024 bytes with an exponential increase of data rates start from 64Kbps to 1Mbps.

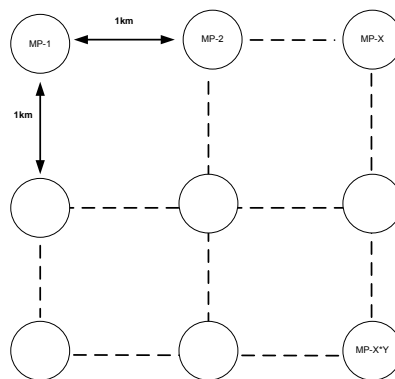


Figure **Error! No text of specified style in document..**1 Topology for scalability performance

The graph analysis of throughput average is presented in figure 3.8. For the overall performance, OLSR gives slightly higher throughput than AODV and HWMP in a multi-hop network. While at the lower data rate up to 300 Kbps, the performance of three routing protocols had approximately the same average throughput, the performance of both HWMP and AODV decreased as the load increased for 25% from OLSR throughput.

The lower maximum throughput of reactive selection for HWMP and AODV is explained by falsely detect the loss of data packets as congested link and remove the path from its routing list accordingly. The reactive routing then proceeds to trigger another path discovery. Unlike OLSR, the routing mechanism to forward the data packet only required a reply up to second hop neighbor without waiting the message reply from destination and stored any route information in MP.

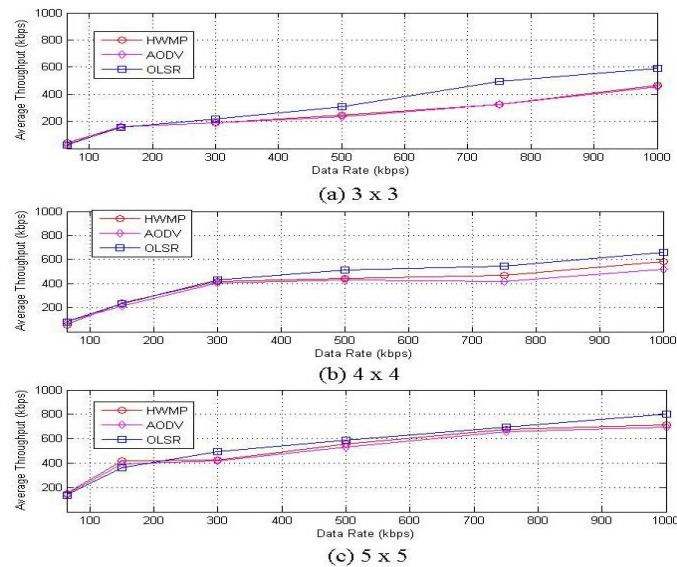


Figure Error! No text of specified style in document..2 Performance analysis of throughput average for (a) 3x3 grid (b) 4x4 grid (c) 5x5 grid MPs

The comparison between AODV and HWMP are not giving any much differences, even the HWMP perform slightly better in greater grid. The airtime metric in HWMP detects any possibility error rates due to data traffic collusion. It gives the better link connection throughput 3% higher for the data flow than traditional distance vector of AODV.

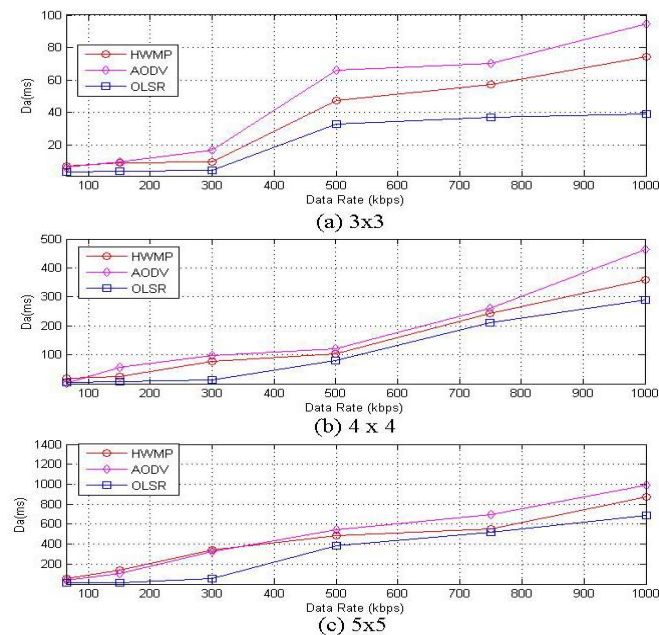


Figure Error! No text of specified style in document..3 Performance analysis of delay average for (a) 3x3 grid (b) 4x4 grid (c) 5x5 grid MPs

As seen in figure 3.9, the average end-to-end delay comparison shows that OLSR perform significantly than reactive routing. The reactive mechanism conducts a path discovery when the data packet arrives at the path table time out. There is a queue time in the source

MP, waiting the request reply from destination. Hence, it takes amount of time to flow to the intended destination. OLSR gives the advantages in average 23% of having routes immediately available when needed due to its proactive nature and using only selected nodes MPR to retransmit control messages periodically. Although OLSR gives the complete table before delivering data transmission, its limitation to handle higher amount MPs is slightly reduced. The reactive mechanism requires a slow start to establish its path, but it stable when the amount of data is increase in time.

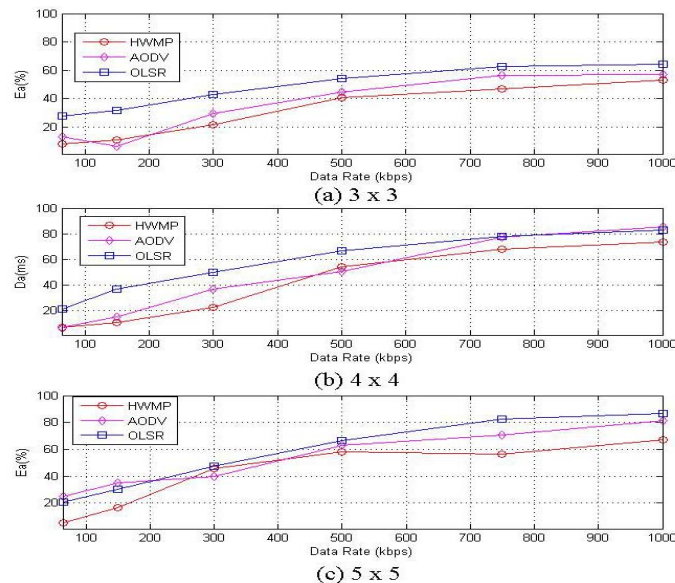


Figure Error! No text of specified style in document..4 Performance analysis of error rate average for (a) 3x3 grid (b) 4x4 grid (c) 5x5 grid MPs

The reactive comparison of AODV shows that delay difference is higher than HWMP. This is caused by the route discovery induced by both protocol. The AODV mechanism floods the route request message if there is no reply from the destination, especially in the congested path. It increases the contention windows of waiting reply in source MP before sending the data packet. The layer 2 mechanism in HWMP gives the priority of PREQ packet to be process in intermediate MP even the link is saturated with packet queuing. In some occasion, the higher delay of HWMP than AODV is caused by the airtime metric to avoid links being used and find the longer path even it has more delay.

In terms of packet error rate, figure 4.9 shows HWMP gives the best result. HWMP is calculating its routes using airtime metric where it senses the link error rate better than AODV and OLSR.

#### 4. Conclusion

The variation for all performance parameter result shows that the proactive routing protocol of OLSR maintained the transfer time of telemedicine data traffic. The OLSR protocol gave the smallest time variation of delay and jitter rather than HWMP and AODV in various hop number and data rates. Overall, HWMP performance is more stable than other protocol. The higher data rate and hop count; HWMP could achieve almost the same performance than OLSR. In terms of the package loss rate, HWMP as the most effective routing protocol needs to be improved as the reliable communication protocol of telemedicine system data using WMN. This result indicates that further refinement of 802.11s based HWMP standard is required to reaches the performance for QoS traffic of telemedicine service.

#### References

- [1] P. Nanda and R. C. Fernandes. *Quality of Service in Telemedicine*. ICDS'07, First International Conference n the Digital Society, Guadeloupe. 2007: 2.

- [2] C. S. Pattichis, *et al.* Wireless telemedicine systems: an overview. *IEEE Antennas and Propagation Magazine*. 2002; 44: 11.
- [3] H. S. Ng, *et al.* Wireless technologies for telemedicine. *BT Technology Journal*. 2006; 24: 130-137.
- [4] R. S. H. Istepanian, *et al.* *M-Health Emerging Mobile Health Systems*. Springer Science+Business Media, Inc. 2006.
- [5] E. Micheli-Tzanakou, *et al.* *Ubiquitous M-Health Systems and the Convergence Towards 4G Mobile Technologies*. M-Health, R. S. H. Istepanian, *et al.*, Eds., ed: Springer US. 2006: 3-14.
- [6] Y.-Y. E. Tan, *et al.* *Fragility issues of medical video streaming over 802.11 e-WLAN m-health environments*. 28th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, New York. 2006.
- [7] A. Jamal, *et al.* *Role of Telemedicine during disaster: A Case Study*. 9th International Conference on e-Health Networking, Application and Services, 2007 Taipei, Taiwan. 2007.
- [8] Z. Wang and H. Gu. A review of telemedicine in China. *Journal of Telemedicine and Telecare*. 2009; 15: 7.
- [9] J. Bicket, *et al.* *Architecture and evaluation of the MIT Roofnet mesh network*. 2005.
- [10] S. Roch. Nortel's Wireless Mesh Network solution: Pushing the boundaries of traditional WLAN technology. *Nortel Technical Journal*. 2005; 2.
- [11] X. Wang. Wireless mesh networks. *Journal of Telemedicine and Telecare*. 2008; 14: 401-403.
- [12] N. Versel. *Tucson shuts down ambulance-based telemedicine network*. *mobihealthnews.com*, ed. Tucson: mobihealthnews.com. 2011.
- [13] A. A. Pirzada, *et al.* SafeMesh: A wireless mesh network routing protocol for incident area communications. *Pervasive and Mobile Computing*. 2009; 5: 201-221.
- [14] A. Yarali, *et al.* *Wireless mesh networking: A key solution for emergency & rural applications*. Advances in Mesh Networks, 2009. MESH 2009. Second International Conference on. 2009: 143-149.
- [15] R. Martí, *et al.* Providing early resource allocation during emergencies: The mobile triage tag. *Journal of Network and Computer Applications*. 2009; 32: 1167-1182.
- [16] E. Supriyanto and H. Satria. *A novel low cost telemedicine system using wireless MESH network*. 3rd South East Asian Technical University Consortium (SEATUC), Johor. 2009.
- [17] I. H. Mulyadi, *et al.* *Wireless medical interface using ZigBee and Bluetooth technology*. Modelling & Simulation, 2009. AMS'09. Third Asia International Conference on. 2009: 276-281.
- [18] I. H. Mulyadi. *Hybrid zigbee-bluetooth communication protocol and adaptive bandwidth allocation algorithm for telemedicine application*. Universiti Teknologi Malaysia, Faculty of Electrical Engineering. 2012.
- [19] S. Kun, *et al.* *Path loss models for suburban scenario at 2.3 GHz, 2.6 GHz and 3.5 GHz*. Antennas, Propagation and EM Theory, 2008. ISAPE 2008. 8th International Symposium on. 2008: 438-441.