

## 802.11s QoS Routing for Telemedicine Service

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### ABSTRACT

The merits of 802.11s as the wireless mesh network standard provide a low cost and high independent scalability telemedicine infrastructure. However, challenges in degradation of performance as hops increase and the absent of Quality of Service (QoS) provision need to be resolved. The reliability and timely manner are the important factor for successful telemedicine service. This research investigates the use of 802.11s for telemedicine services. A new model of 802.11s based telemedicine infrastructure has been developed for this purpose. A non deterministic polynomial path selection is proposed to provide end-to-end QoS provisioning in 802.11s. A multi-metric called QoS Price metric is proposed as measurement of link quality. The QoS Price is derived from multi layers values that reflect telemedicine traffic requirement and the resource availability of the network. The proposed solution has modified the path management of 802.11s and added resource allocation in distributed scheme.

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## 1. INTRODUCTION

The main goal of QoS Routing is to select the reliable and dependable paths of single to multi-hop nodes to be used by the flow of packets from source to destination. The QoS mechanism in WMN should be design to support differentiation of multiple service requirements and providing hard guarantees for critical services. These QoS requirements are determined by the upper layer of routing protocol, such as packet error rate, throughput and end-to-end delay requirements, which are crucial for the success application. The WMN routing protocol will gather the information parameter from the lower layer, such as transmission rate or delay from physical layer, to determine the correct flow to destination. The effective routing to support QoS of upper layer could be done effectively in cross-layer design. It could be accomplished by better reflecting adjacent layer variations onto routing metrics [1].

802.11s is aimed at guaranteeing connectivity by building multihop stationary MPs as backhaul and MBSS roaming among them. Consequently, mobility and energy saving in mesh network are not substantial issues than link quality, such as capacity or error probability. These differences from ad hoc or common WLAN make hop count metric not appropriate to estimate the good path parameter in 802.11s. The selection of path based on minimum path could lead to suboptimal performance of longer range links with marginal quality. 802.11s could use the benefits more on quality-aware metrics that could improve utilizations of wireless resources on the selected paths [2].

### 1.1. 802.11s Routing Metric

Default routing metrics in 802.11s amendment defines a link quality efficiency by using airtime cost metric.[3] MP's discover the peer candidate other MP in default doing passive scanning by listening beacon frames. Another method of peer discovery is done by transmitting probe request frames. Both methods use the same calculation of airtime cost. Airtime cost is the amount of consumed channel resources calculated

when transmitting a frame over a particular wireless path. The best path to given destination is selected by the minimum air time cost of  $C_a$  among candidate path, with the calculation as

$$C_a = \left[ O_{ca} + O_p + \frac{B_t}{r} \right] \frac{1}{1 - e_{pt}} \quad (1)$$

where  $O_{ca}$ ,  $O_p$  and  $B_t$  are channel overhead, protocol overhead and number of bits in a fixed 1 kilo-byte test frame, respectively. These parameters are been taken from link layer of 802.11 technology. The transmission bit rate  $r$  in Mbit/s is the rate at which the mesh point would transmit a frame of size  $B_t$  with frame error rate of  $e_{pt}$ , based on the current conditions of the radio environment with  $r$  is bit rate of modulation and coding method in physical layer. This metric could describe the dynamic wireless environment impact to WMN path in lower layer. The use of fixed size of the probe creates the overhead especially in large scale network and less accurate compared with the real data packet size.

The work by Campista *et al.* [1] describes the preliminary comparison between quality-aware metrics for wireless mesh network. The author has also described its advantages and issues in each metric with 6 components needed for maintaining link quality performance. We adopt this list by removing data rate and packet size components; and introducing the additional traffic load components and the working layer. The end-to-end traffic in wireless mesh network tends to flows forward to gateways or away between MPs. The routing metrics should be aware of the load along the flow to avoid congestion in selected path and depict the load by allowing the routing algorithm to calculate paths that provide load balancing.[4] The traffic load could be measured by routing metrics that provide the number of flows and queue size. The number of flows includes the data rate as calculation mechanism with the data packet size used by queue size calculation. This new comparison list could be seen in Table .

Quality aware routing metrics use observations of frame delivery, signal strength and any parameters which could lead to performance problems. Routing metrics observes the estimation and adaption from most parameters in physical layer. In practical, it is hard and very complex to handle channel quality issues in its implementation. Most IEEE 802.XX standards depend on simple computation strategy based on variance detection of error in small number of link-layer frame transmission.

Table 1. Comparison of routing metrics in wireless mesh network

Metric	Quality-Aware	Traffic Load	Intra-flow interference	Inter-flow interference	Medium instability	Working Layer
Hop	x	x	X	x	x	Network
ETX	✓	x	X	x	x	Network
ML	✓	x	x	x	x	Network
ETT	✓	✓	x	x	x	Network
WCETT	✓	✓	✓	x	x	Network
MIC	✓	✓	✓	✓	x	Network
mETX	✓	✓	x	x	✓	Network
ENT	✓	✓	x	x	✓	Network
INX	✓	✓	x	✓	✓	Network
iAWARE	✓	✓	✓	✓	✓	Network
CATT	✓	✓	✓	✓	✓	Network
RARE	✓	✓	✓	✓	✓	Network
Airtime Cost	✓	✓	x	x	x	Link

Expected Transmission Count (ETX) use the number of forward and reverse packet transmission success to a MP neighbor [5]. Each MP periodically broadcast a probe packet with the total of received probes from each neighboring MPs. The number of ETX is a calculation of delivery ratio on both forward probes and its reverse ACK frame at the last T time interval. The route selection will be done by minimum cost of sum ETX along path to destination. Even though ETX metric could describe multiple link layer metrics, it could not capture packet loss variations.

Minimum Lost (ML) metric is similar with ETX in terms of computation of probing packet delivery ratio. ML only calculates the end-to-end loss probability, makes it more efficient probe sending than ETX. The probe packet in ETX and ML is smaller than typical data packet and performed at minimum rate. This derived a drawback on estimating link bandwidths and performance on high rate wireless network [5].

Expected Transmission Time (ETT) periodically calculates the time of data packet required to be transmitted successfully to each neighbor. The ETT data packet varies in size of packet sequence. The variation is based on the result of estimated bandwidth. It computes bandwidth availability by dividing the large packet with the minimum delay received. The ETT selection of the best path is similar with ETX, by choosing the minimum cost of ETT values along the path.

The Weighted Cumulative ETT (WCETT) modifies ETT to consider intra-flow interference by summing end-to-end delay and its channel diversity. WCETT does not consider inter-flow interference because it must consider all channels along its final path to avoid intra-flow interference. Thus, WCETT final path could end in congested areas.[6]

The metric for interference and channel switching (MIC) takes several interfering MP in its neighborhood and estimates inter-flow interference. MIC calculates its minimum cost based on ETT metric and using virtual MP to normalize its minimum-cost computation. The interference calculation accuracy using virtual MPs to collect interference information is still questionable. It is hard to introduce virtual MPs to represent multiple channel environments.[6]

Interferer Neighbors Count routing metric (INX) also extends ETX metrics. The INX metric tries to overcome interference by adding sum of transmission rate of links between neighboring MPs. The link between two MPs is assumed as asymmetric link to define the set of interfering neighbors. The selected path is based on the minimum cost of INX calculation of MPs along the path. Interference aware (iAWARE) uses signal to noise ratio (SNR) and signal to interference ratio (SINR) to calculate interference variations of a MP and its neighboring MPs [7]. Unfortunately, the use of global information of maximum number co channel interference is difficult to be gathered without using flooding message.

The Resource Aware Routing for Mesh (RARE) uses a passive monitoring technique to measure link quality. This metric utilizes bandwidth to measure traffic load and Received Signal Strength Indicator (RSSI) for interference measurements [8]. RARE is the first metric to measure traffic load and its interference by using passive monitoring that reducing the overhead transmission in its implementation. The drawback of RARE is the use of physical parameter RSSI which does not accurately describes the fluctuations of interference in high rate wireless transmission [9]. Moreover, passive monitoring in RARE could not depict the accurate information on link quality when the data traffic is low.

The Contention-Aware Transmission Time (CATT) adopts ETT metric by identifying interference influences on packet transmission time [10]. The metrics use both type of messages to exchange the transmission rate between MPs and assumes a worst-case approach to estimates the interference. This assumption gives an overestimate calculation on the link quality results and physical value of delay transmission variance could not capture the traffic load accurately.

Various routing metrics have been identified and classified by their measurement ability to ensure link quality. Most routing metric gathers the information from physical layer parameters and could be achieved by using passive monitoring. There are some parameters, such as transmission rate, need to be measured by using active monitoring. This active monitoring could use fixed size probes or provided messages type provided by routing protocol. Most quality aware routing metrics try to capture link-performance parameter by using calculation in the network layer. These schemes can be enhanced by validating the parameter directly from the link layer and use a measurement method in network layer. This combination need to involve cross-layer interaction as shown in several routing metrics.

## 2. SYSTEM MODEL FOR TELEMEDICINE SERVICE

The requirements on telemedicine services are largely dependent on the type of its application and devices data acquisition approach. In telemonitoring, the primary communication is based on transferring several vital signals simultaneously and continuously for physiological parameters monitoring such as heart rate, blood pressure, Oximetry and others signal. In the current technology trend, sophisticated two way communications using video and audio, and also diagnostic image sensor could increase the traffic load in the network. Telemonitoring service is usually done in push-forward transfer from patient in real time manner. Many other applications also use an occasional approach to reduce the data load with the assumption that only major changes of data signal are being transferred or by request from both patient and the remote specialist.

In general, we can segregate telemedicine communication into two categories with the criterion of the bundle of data transmission. All of these services are shown in figure 1 as comprehensive telemonitoring seeing in patient domain.

First category is called as the intermittent monitoring where acquisition of data per incident or occurring at intervals in short term transfer but not limited in a single packet transfer. It includes the data that occasionally requested by medical such as diagnostic still images, diagnostic video or conversation in short

time. The sporadic or long periodical check-up such as SpO<sub>2</sub> or ECG with time interval sampling are also in this category. On-demand services by using still image or video when it is required. These on-demand services are controlled by healthcare personnel sites application on initialization. On the established connection, both patient and healthcare personnel sites will control the quality of the data transfer. Required service is generated commonly by healthcare sites, while in an emergency situation patient site could push the data to healthcare sites.

Second category is continuous monitoring, where the data need to be transfer as long the monitoring session happen between both parties. ECG and other vital sign devices data are usually done in continuous and burst transmission to the healthcare personnel or hospital receiver. The access to real-time monitoring of vital sign and other patient EHR as continuous data source are the examples of this continuous monitoring. These data sources are controlled individually at patient site, as a tool for aggregating data for primary use for diagnosis.

Each category has a special design for emergency monitoring. An emergency signal from a device application has a different data traffic approach. It needs to be delivered in real time with even in the loose delay requirement application. This will allow physiological data directed instantaneously to the remote healthcare. Assume that in remote patient  $p$  is installed with a packet of monitoring device application  $N_{device}$  and attached to a Mesh Client. Each devices  $N_{device}$  is belong to one of categories with its own requirement constrains. All of devices and has been determined and set by healthcare personnel by using sort of application before it can be use.

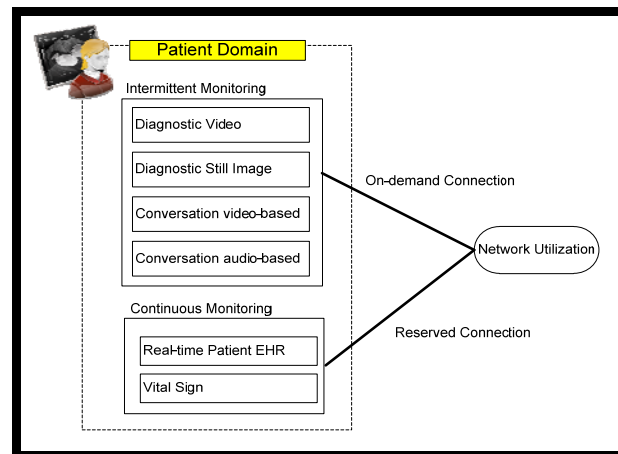


Figure 1. Comprehensive telemedicine application on Patient domain

Both categories communications process are intrinsically non-deterministic where data transfer for each device application is based on the unpredictable condition of system network and receiver request. This stochastic process is happened for all of the input from source node, which not always equals with the output at receiver node and involved several random values, such as noise. A reactive communication between sender and receiver node is done with sporadic access to network resources and could be determined by probabilistic action at nodes.

### 2.1. Device Traffic Parameter

The requirement parameters for the experiment are determined by upper-layer telemedicine service. Each application in telemedicine service will be delivered in different requirements posed on end-to-end communication system. These requirements is varied because different level of performance. The issue on disagreement on parameter values leads to the uncertainty of qualitative bounds for performance. The selected parameters for each device traffic pattern are shown in Table 2. The details of each encoding algorithm and upper-layer protocol workflow are not required. This research only focuses on finding the calculation parameters for the required parameters in lower layer

Table 2. Selected device traffic parameter

Data Type	Traffic Type	codec	Application Performance		
			D (ms)	T (kbps)	E (%)
Diagnostic Video	Intermittent	H.264/MPEG-4 AVC	300	2,000	<3%
Diagnostic Audio	Intermittent	AAC	50	68	<1%
Diagnostic Image 1	Intermittent	JPEG-LS	15000	200	0.10%
Diagnostic Image 2	Intermittent	JPEG Baseline	15000	50	0.10%
Vital Sign 1	Continuous	ECG vector	500(n) 250(cr)	96	0.10%
Vital Sign 2	Intermittent	BP,HR,SpO <sub>2</sub>	500(n) 250(cr)	8	0.10%
Teleconf Audio	Intermittent	G.729a	50	32	1%
Teleconf Video	Intermittent	H.263	300	64	3%
Other Traffic	Intermittent	HTTP	1000	12	0.10%

2.2. Wireless Mesh Network Infrastructure

Consider our Telemedicine infrastructure scenario in figure 2, MP-D through MP-H are a set of  $n_{mp}$  of wireless mesh points, denoted as  $V_{mp} = \{v_{mp} | mp = 1, 2, \dots, n_{mp}\}$ . MP-C and MP-A are a set of  $n_{mpp}$  of wireless mesh points portals denoted as  $V_{mpp} = \{v_{mpp} | mpp = 1, 2, \dots, n_{mpp}\}$ . Overall mesh network infrastructure for telemedicine is a combination from mesh point and portals, denoted as  $V = V_{mp} \cup V_{mpp}$ .

We took an arbitrary node of MP-H as a single mesh point, where it has several one-hop  $mp$  neighbors within its transmission range. We assume that transmission from each  $mp$  in  $V$  has fixed range. If MP-H denoted as  $k$ , then MP-H has  $MPN_k$  of one hop neighbor then  $mpn = 1, 2, \dots, MPN_k$ .

Each  $mp$  maintains its resource management by controlling queues from each transmission link. The arrival packets from  $MPN_k$  neighbors in MP-H are considered in their own queue according to their pre-determined link. The coordination scheme of channel access is based on Time Division Multiple Access (TDMA) by dividing each queuing into fixed time slot. The controlled distribution in each  $mp$  is assumed synchronized to the guard period from slot boundaries.

In one time frame consists of control phase for control message and transmission phase for data message. The slot for control phase has  $f_c$  fixed size time slot and  $f_d$  fixed size time slot for data. At the beginning of the control frame, scheduling decision is determined by all nodes and relatively unchanged until the next time frame.

The interference channel is assumed has relatively constant block size during period of one time frame. We also assume that each  $mp$  is equipped with to solve the wireless medium interference problem. We neglected the power control difference among the  $mp$  where each channel transmission has the same fixed transmission power measurement.

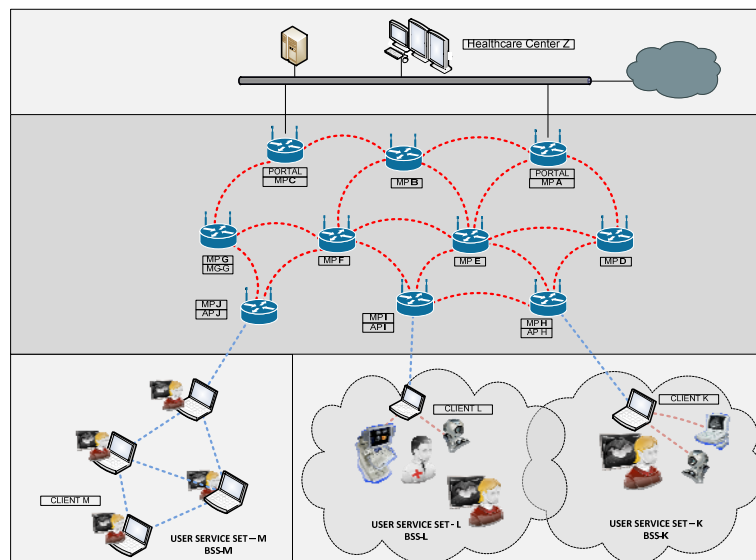


Figure 2. Wireless Mesh Network Scenario for Telemedicine Application

### 2.3. Path Model

In this model MP-H is connected to the telemedicine client and requests a connection session to the other  $mp$  as destination. This request will generate a session of packet transfer, and through a set of selected link called path. We assume that the data flow from an  $mp$  to another follow the M/M/1/K of IEEE 802.11 model. The properties of the data flow in this model is a Poisson distribution with rate  $\lambda$  and the probability of occurring in the fixed time interval slot of  $\{f_c, f_d\}$  and independently generated on each  $mp$ . The job service time for the queue process in each MP have an exponential distribution with rate  $\mu$  with the limit of slot size. That means if a new packet arrives and the queue already in  $K$ th slot, then this new packet is dropped.

We denote  $\pi_{xy}$  is the possibilities of path set for data flow from source of MP-X to destination MP-Y. As describes in figure 5.2, a path is a multi set positive of end-to-end joined links series from one MP-X to another MP until MP-Y. The  $\pi_{xy}^k$  is a concatenated result of a set links of  $\{(mp_i, mp_j)\}$  where all  $\{(mp_i, mp_j)\}$  is a member of  $V_{mp}$  and/or  $V_{mpp}$ . We could formally express the path of data flow from data source MP-X to destination MP-Y at the  $k$ -th path as:

$$\pi_{xy}^k = \{ \cup \{ (mp_i, mp_j) \} | \forall (mp_i, mp_j) : V \} \quad (2)$$

where  $k = 1, 2, \dots, K$  is the number of possibilities route.

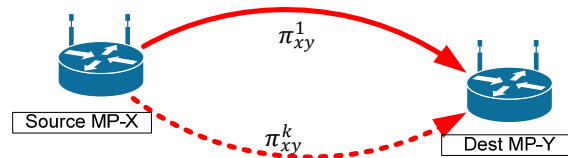


Figure 4. Possibility of path from source MP-X to destination MP-Y

### 2.4. QoS Price as Multi-Metric Performance

The complexity of path computation should not disable the scalability of the 802.11s network. The computation should also be able to work in centralized and distributed environment. The metric should catch the characteristic of the network. It should possible to support basic QoS requirements. If multi Metric implementation is needed, then each metric in the metrics set should be linearly independent and orthogonal from each other. This orthogonality is important to reduce the redundant information between the metrics and substantially reduce complexity of path computation. Each metric should be objective measured at the service point and related to network performance parameters.

To get the information and loosely coupled exchange between PHY, MAC and network layer, we defined QoS utilities in unified cross layer approach for achieving best performance of upper layer QoS requirements.

We define the multiple QoS metric as **QoS Price Ratio**, denoted as  $\mathcal{C}$ . The QoS Price Ratio will be expressed by each selected metrics as measurement over QoS requirement. By considering a range of  $N_{device}$  of telemedicine service connected to the network and the parameters that govern the satisfaction for these services, a classification of QoS categories should be determined by QoS Price Ratio.

The selected impacting parameters are delay, throughput and probability of error rate as the key parameters to fulfill these requirements. These three metric are already proven as non deterministic polynomial time completeness (NP-complete) where the composition of rules follow additive, multiplicative and concave composition rule.[11, 12] We assume that other key impacts, such as delay variation or jitter, will be considered by buffering solution of transport layer even for the telemedicine service that intolerant of delay variation.

Consider a link session of  $q$  with three QoS requirements, such as delay, throughput and packet error rate (PER). The proposed QoS Price Ratio for this session, where price of end-to-end delay, throughput and probability of error rate respectively, could be describes as:

$$\mathcal{C}(q) \rightarrow (\mathcal{C}^D(q), \mathcal{C}^T(q), \mathcal{C}^E(q)) \quad (3)$$

Each metric has own interest cost from its original QoS Price Ratio denoted as  $\alpha$ . This interest cost factor is introduced to provide a cost margin from the less accurate estimation in a metric measurement.

### Price of Delay

Delay manifests itself in a number of ways and has a very direct impact on telemedicine service satisfaction. The end to end delay is assumed to follow additive composition rules of metrics as the sum of link delay from one  $mp$  to another in a route. The measurement of end to end delay of packet price for route  $\pi_{xy}^k$  is defined as the sum of actual delay measurement from all links  $\{(mp_i, mp_j)\}$  in a path  $\pi_{xy}^k$ , expressed as

$$D_{k \in xy}^a = \sum_{(i,j):\pi_{xy}^k} (Dq_{ij}^a + Dt_{ij}^a) \quad (4)$$

The best adoption on the calculation of available delay could be seen in [13]. The available delay on a specific  $\pi_{xy}^k$  path is composed from two types of delays. First, the queue waiting time in  $f_{c,d}$  time slots as the average time the traffic packet enters in the queue and passed it to the MAC layer. We denoted average queuing time for link  $\{(mp_i, mp_j)\}$  as  $Dq_{ij}^a$  calculated in  $mp_j$  by:

$$Dq_{ij}^a = \begin{cases} \frac{\rho}{1-\rho} \frac{1 - (K+1)\rho^K + K\rho^{K-1}}{1-\rho^K}, & \rho \neq 1 \\ \rho = 1 - \frac{k}{2\lambda}, & \rho = 0 \end{cases}$$

where  $\rho = \frac{\lambda}{\mu}$ ,  $K$  is the slot size and  $\lambda$  is the transmission rate of packet arrival.

The parameters for each 802.11 physical layer are listed in table 5.1. The average transmission delay from the link  $\{(mp_i, mp_j)\}$  can be obtained by additional factor of the backoff and successful transmission packet. The average transmission delay of  $Dt_{ij}^a$  is calculated as :

$$Dt_{ij}^a = \overline{backoff} f_{ij}^a * f_c + \sum_{k=0}^n (DIFS + T_m)$$

The DCF inter-frame Space is added as the sensing time before the wireless medium transmitting and  $T_m$  for the time of a packet needed for transmitting of  $m$  bytes successfully.

Table 3. Parameter of the different 802.11 physical layer

Parameter	802.11 (FHSS)	802.11 (DSSS)	802.11b (HR/DSSS)	802.11a (OFDM)	802.11g (ERP-OFDM)
$f_c$ ( $\mu\text{sec}$ )	50	20	20	9	9
$SIFS_{size}$ ( $\mu\text{sec}$ )	28	10	10	16	16
$PIFS_{size}$ ( $\mu\text{sec}$ )	78	30	30	25	36
$DIFS_{size}$ ( $\mu\text{sec}$ )	128	50	50	34	56
$f_{operation}$ (GHz)	2.4	2.4	2.4	5	2.4
$\lambda_{max}$ (Mbps)	2.0	2.0	11.0	54.0	54.0
$CW_{min}$ (unit)	15	31	31	15	15
$CW_{max}$ (unit)	1023	1023	1023	1023	1023

The required delay state from upper layer is expressed as  $D_q^r$  with its interest factor of  $\alpha^D$ . The required delay state should be a variable range with the cost of delay is formulated as :

$$C_k^D(q) = \frac{D_{k \in xy}^a}{(1 - \alpha^D) D_q^r} \quad (5)$$

### Price of Throughput

The throughput in a link is the average rate of successful packet delivery from one node to others. By assuming the measurement is done proactively and periodically of  $mp$  for each link every  $\Delta t$  interval. The

802.11s beacon frames provides the sensing framework per time units. By adding the  $t_{hmesh}$  as header overhead of 802.11s, the calculation of available throughput could be done by:

$$T_{ij}^a = \frac{t_{1500}^a}{(DIFS + SIFS + t_m + t_{hmesh} + \overline{t_{busy}})} \quad (6)$$

where  $t_{1500}^a$ ,  $t_m$ ,  $t_{busy}$  as transmission time of test package size 1500 bytes, the entire data frame and the interval of transmission channel in busy state.

Here, throughput follows the concave composition rule, where the least throughput is taken as bottleneck link from all links  $\{(mp_i, mp_j)\}$  in  $k$ -th path. It is formulated as  $T_{k \in xy}^a$ , where:

$$T_{k \in xy}^a = \min_{(i,j):\pi_{xy}^k} T_{ij}^a \quad (7)$$

The required throughput state from upper layer is expressed as  $T_q^r$  with its additional price factor of  $\alpha^T$ . The price of throughput is formulated as:

$$C_k^T(q) = \frac{(1 + \alpha^T)T_q^r}{T_{k \in xy}^a} \quad (8)$$

### Price of Error Rate

A packet in  $mp_y$  received from  $mp_x$  may possibly be corrupted by interference and distance from the other network. It is decided by the amount of packet transmission successfully received by the destination. The packet is successfully received when the  $mp_y$  physical layer at the IDLE state and the energy of the packet  $k$  is higher than  $mp_y$  energy detection threshold. The information of the error rate in 802.11s depends on the 802.11 lower MAC layer statistic calculations. The MAC layer of 802.11

The composition of Probability of Error Rate follows the multiplicative rule, as a result of multiplication of all error rate of links  $\{(mp_i, mp_j)\}$  for a route  $\pi_{xy}^k$ . The formula of packet error rate (PER) over a route  $\pi_{xy}^k$  is formulated as

$$E_{k \in xy}^a = 1 - \prod_{(i,j):\pi_{xy}^k} (1 - E_{(i,j):\pi_{xy}^k}^a) \quad (9)$$

The required PER state from upper layer is expressed as  $E_q^r$  with its interest factor of  $\alpha^E$ . The price of PER is formulated as :

$$C_k^E(q) = \frac{E_{k \in xy}^a}{(1 - \alpha^E)E_q^r} \quad (10)$$

For the multi metric QoS price ratio, a source to destination data flow will be feasible if and only if fulfill the QoS Price Ratio less than 1. The selected path of  $k \in xy$  need to fulfill the formulated formula as :

$$(C_k^D(q), C_k^T(q), C_k^E(q)) \leq \mathbf{1} \quad (11)$$

### Path Selection

The scenario of telemedicine involves multi application with different requirements of cost  $C$ . An ECG application does not require a guarantee in  $C_k^T(q)$  as long the  $C_k^D(q)$  of delay cost could be achieved. The indicator function will differentiate the application requirement for service guarantee where the telemedicine service requires only part of the metrics. The critical indicator is denoted with as  $I_m$ , where  $\mathbf{m} = \mathbf{D}, \mathbf{T}, \mathbf{E}$ , expressed as:

$$I_m = \begin{cases} 1, & m \text{ critical} \\ 0, & \text{otherwise} \end{cases} \quad (12)$$



The critical indicator  $I_m$  and its interest cost factor of  $\alpha^m$  is mapped to entire selected intermittent and continuous transmission categories. As in table 4.2, the indicators and interest cost factors values are chosen representing the traffic describes in section 4.2.

Table Error! No text of specified style in document.. QoS Mapping from telemedicine traffic categories to QoS Price Metrics

	Intermittent Monitoring	Continuous Monitoring	Intermittent Critical	Continuous Critical
$I_D, \alpha_D$	1,variable	0, -	1,variable	1,variable
$I_T, \alpha_T$	0,-	1, variable	0,-	1,variable
$I_E, \alpha_E$	0,-	0,-	1, variable	0,-

Our multi-metrics value selection based on QoS Price metric in route  $\pi_{xy}^k$  can be formulated as:

$$U_{xy}^k = \max_{D,T,E \rightarrow metrics} [I_D C_k^D(q), I_T C_k^T(q), I_E C_k^E(q)] \quad (13)$$

and the path selection mechanism for decision function is given by :

$$S(k^*) = \min_{\pi_{xy}^k: \pi_{xy}} U_{xy}^k \quad (14)$$

where route  $\pi_{xy}^{k^*}$  is the selected route from all proposed routes from source MP to destination MP.

## 2.5. Resource Allocation

Although the interaction of standard module 802.11s is done in layer 2, their interactions with other MAC functionality, especially medium access mechanism are not considered. A strategy implementing this routing is actually losing one important advantage of layer-2 routing, i.e. resource allocation and its admission control. It need a parameter exchange from routing mechanism to its management of resources provided by MAC layer design [14].

As the 802.11s topology is distributed, there is no scheme specified in 802.11s for the local rate control. Simply by adjusting EDCA parameters cannot achieve the goal because EDCA is not effective to ensure a certain required traffic size. As in 802.11s optional MCCA mechanism, the slot number and reservation request from MCCA setup not directly coherent with routing mechanism.

Our objectives for resource control in 802.11s is to definite a long run utilization control of m by representing the communication from proposed traffic categories in mp client. The appropriate of utilization of a link is based on a policy in the function cost of  $C$  for the decision maker at the MAC layer by deciding the right cost  $c(s)$  at the transition state from one traffic categories to others. The proposed resource control shall use resources as efficient as possible, by considering that the cost will increase as the longer hop in 802.11s and the wireless channel fluctuation. It is desirable for MAC layer control to enforce the required QoS Price by achieving its relative target scaled by per-node constantly or “close to target QoS”. So if the required metric from QoS Price is  $M_q^r$ , then our objectives as:

$$M^{alloc}(mp_k) \approx (1 \pm \alpha^M) M_q^r \quad (15)$$

The means of our resource control is the reservation of the slot number which allocates all packet with QoS price ratio scheme on MAC layer. MAC layer in 802.11s as in 802.11 is based on distributed mechanism. It will be sufficient focusing at a single MP to find the derivate allocation based on QoS Price. By adopting the calculation of slot reservation from [15] on MAC layer, the intended mp should reserve  $N_{k \in xy}^s$  slot numbers as describes in equation (15) as:

$$M^{alloc}(mp_k) \approx N_{k \in xy}^s = \left\lceil \frac{N_{pkt} X (t_k^{pkt} + t_k^{ack} + (2 X t^{SIFS}))}{t^{slot}} \right\rceil \quad (16)$$

The resource allocations calculations should be verified at each  $mp$  along path of  $\pi_{xy}^{k^*}$  during the path discovery phase. The resource allocations of  $N_{k \in xy}^s$  slot for  $\{(mp_i, mp_j)\}$  links in  $mp_k$  along  $\pi_{xy}^k$  path are done after each intermediate  $mp$  received PREP of  $mp_x$  from the  $mp_y$  destination. During the time of

forwarding PREQ and waiting PREP message, the other link could use the intended pre-reserved slot. It will be avoid the false detection of failed reservations when it receives the PREP message.

### 3. RESULT AND ANALYSIS

There is no doubt that Network Simulator 2 (ns-2) is the most used as simulation tools among wireless network researchers [16]. It is based on the open-source model under GPLv2 license. This open source paradigm is a part of its success with extensive contribution of extension and features by computer network community. It provides many model set and implementation of network protocols and algorithms. ns-2 maintenance has been stopped since 2011 and is not being accepted for publication, even still in heavy use with average 10,000 downloads per month in 2013 (source: <http://sourceforge.net/projects/nsnam/>). However, the ns-2 shortcoming and the need to improve the realism of the real system model encouraged a developer team funded by U.S. National Science Foundation to develop a replacement for ns-2, called ns-3. In its development stage, ns-3 is being developed from scratch following a completely different architecture and completely removed the backward-compatibility of ns-2. The ns-3 mesh module is the implementation of 802.11s standard with the additional of Flame routing protocol developed by [17]. This module main attention is to provide layer 2 routing implementation as two tier MAC layer device. The main part 802.11s standard has been implemented in this module, such as the implementation of the Peering Management Protocol, the HWMP and the airtime link metric.

#### 3.1. Experimental Setup

In this section, we perform extensive simulation experiments to analyze the performance of medQoS routing protocol. The effects of many important parameters which are related to the wireless environment are studied. The comparison with 802.11s routing scheme is conducted to show the improvements on the overall performance especially for telemedicine service.

Table Error! No text of specified style in document.. Simulation parameter for medQoS performance

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 Number of Links	2 links
802.11s HWMP Protocol	Maximum PREQ Retries	3
	Path active lifetime	2120 ms
	Root Active lifetime	2120 ms
Channel Model	Propagation Delay	Constant Speed
	Propagation Lost	Kun Path Loss Model
	Carrier Frequency	5.1 GHz
Mesh Device Model	Encoding	OFDM-6Mbit
	Reception Gain	1 dB
	Transmission Gain	1 dB
Mobility	Transmission Power	25 dBm
	Position	Grid Position
	Positioning	Constant

The general simulation parameters that are used in this simulation model are summarized in Table 5. For data traffic generation, source and destination node were selected randomly with the start and stop time follow the exponential distribution. In all experiments we assume the usage of the naïve channel assignment approach.

#### 3.1. Impact of Protocol Overhead

The overhead of a protocol is a cost for the routing algorithm using the available throughput to find the best path according its metric. The overhead introduced by medQoS is 6 bytes length additional to the current 802.11s PREQ message. Simulation is done by using single traffic from  $mp_1$  to  $mp_n$  through  $n-1$  intermediate  $mnp$ . The  $mp$ 's are arranged with  $y$  rows where each row consist of 5 mps. This will be sufficient to find the exact overhead from medQoS routing.

The maximum retries of unsuccessful PREQ reply is 3 with the interval of PREQ is 102.4 microsecond. The destination only flag is set to active mode with no reply and forward from intermediate  $mp$ . The rest attributes for peer management are default. For this experiment, we set the  $I_M$  equals to 1 and  $I_D, \alpha_M$  as 0.5 for  $m = D, T, E$ .

As we can see in figure 5, four medical traffics are simulated with and without medQoS tag. Here, the mean overhead in kbps for each node size are calculated. Overall traffic shows that the overhead is increase when more intermediate mp is added between source mp and sink mp. The overhead for the network, the medQoS-802.11s overhead are higher with the mean of 4.8% for diagnostic audio, 4.86% vital sign traffic, 6.9% for the video, and 7.38% for the teleconference. The teleconference has the highest increase compared with its  $T_r$  and  $D_r$ , while it needs to guarantee both source and sink mp's resource availability. We show that overhead is not significantly increase according with the 16% of additional bytes in PREQ request.

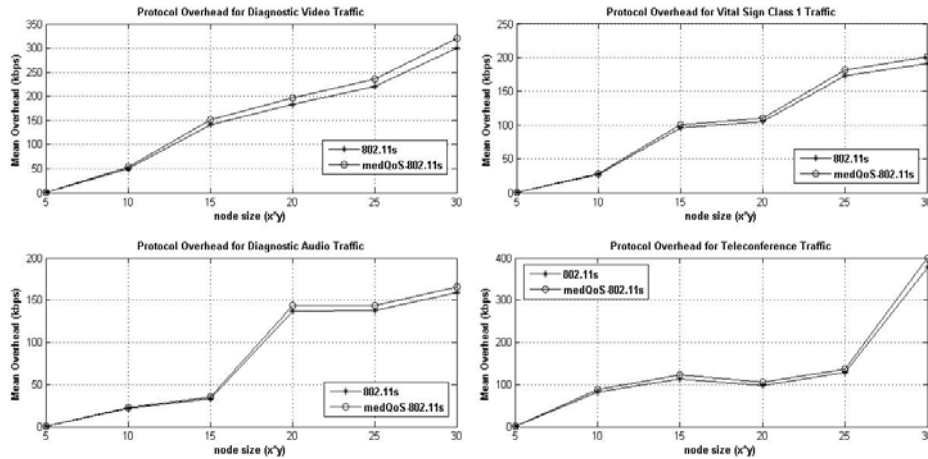


Figure Error! No text of specified style in document.. Protocol overhead of 802.11s and medQoS-802.11s for (a) Diagnostic Video (b) Vital Sign (c) Diagnostic Audio (d) Teleconference

### 3.2. Impact of Concurrent Connections

In this simulation, the number of concurrent connection is increased from 1 to 10 with random source placement to the single destination  $mpp$ . The performance of 802.11s airtime metrics and medQoS metric is tested using a constant mobility mesh point. This network consists of 9  $mpp$ s arranged in 3 x 3 grid with the fixed distance of 1kilometer between nodes. The traffic type is loose by using the same data traffic of diagnostic video with the packet size of 1500 bytes. The simplification was needed by setting the  $I_M$  equals to 1 and  $I_D$ ,  $\alpha_M$  as 0 for  $m = D, T, E$ .

As the numbers of active connections increases, the effect of both inter flow interference and network congestion increase. The more performance degradation will represented by lower network throughput, higher delay, and more probability to adjust the packet loss and error. However, the total degradation will be depends on the used metric and its ability in reducing the effect of the concurrent connection. As shown in figure 6.4a, medQoS can deliver up to 10 percent the data delivered by the standard 802.11s metric especially when the network has more concurrent connections. It means for the required  $T_r$  of 2Mbps, it could guarantee almost 95% for up to 4 concurrent connections. This ensures the ability of medQoS to deal with the traffic increase by adjusting the load among the nodes with the best cost of the alternative link within the grid.

Figure 6c shows that medQoS end-to-end delay is increase slightly than 802.11s airtime metric. The medQoS path discovery tends to find longer paths than airtime metrics as the load increase and was confirmed by the Figure 6b. This is because medQoS tries to look for the lowest cost and wait another PREP reply from the  $mpp$ . As the load increases, especially in the 6 concurrent connections, the medQoS exhibits the highest delay than airtime metrics. This delay is also considered only at the destination packet arrival. So, the airtime metrics has a lower delay due to the lower throughput than medQoS. As a result, medQoS is better than 802.11s airtime metrics. As a distinguish performance for telemedicine application, the medQoS produce lower amount of packet error rate at the destination as shown in figure 6d. The major reason for this behavior is medQoS tend to build more reliable path than airtime metrics. So, medQoS exhibits lower failure rate and lower the packet error add the destination than airtime metric.

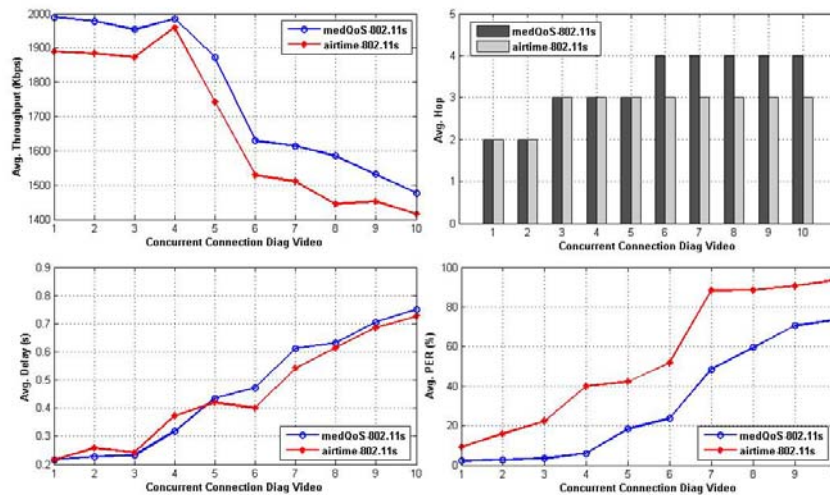


Figure 6. Impact of concurrent connection a. Average throughput b. Average path length c. Average end-to-end delay d. Average Probability of Error.

#### 4. CONCLUSION

In this research, the use of wireless mesh network as telemedicine infrastructure has been presented. A new multi-metric routing protocol for the 802.11s with the data traffic type for telemedicine service has been proposed. The integration of the proposed routing with 802.11s standard has been examined.

The proposed scheme to improve the performance of 802.11s by using join layer optimization is described in details. A new perspective of multi-metric called as QoS Price ratio is introduced to replace the conventional airtime metric of 802.11s. This metric capture the requirement from upper layer and compare it with the available link quality in the physical layer. As the new multi metric model is constructed, the path discovery and decision is adjusted. We called this routing protocol as medQoS routing. Our objective to minimize the changes is done by extending the control message of PREQ and uses the reserve flag bit in PREP message. By following QoS driven resources framework, the resource allocation in the selected path is done in distribution manner along its mesh points. The objective of resource allocation is the maximum affordable resources by mesh point by minimizing the false resource allocation when the PREP from destination is received by the intended mesh point. It should be notes that the path maintenance and resource allocation is changing if another PREQ from the same path request is received.

The test result shows that the overhead introduced by the routing protocol is lower as 7.38 percent for two way communication of teleconference with around 4 to 6 percent for other telemedicine data traffic. In the concurrent connections test with using the greediest resource requirements of diagnostic video, shows that medQoS routing protocol could increase 10% of the required throughput with the guarantee of almost 95% for four concurrent connections. For overall, the reliability of the path for telemedicine service is highly better than conventional 802.11s

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