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A Node QoS-considered Routing Metric Framework for Heterogeneous Wireless Mesh Networks ⋆

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Abstract

Heterogeneous wireless mesh network (HWMN) emerges as a highly integrated, robust and high bandwidth wireless network. Routing metric for HWMN should guarantee the QoS and security of nodes. Routing metric requires two characteristics. First, it is the ability to reflect path quality including nodes and links along the path, which is named node quality and link quality in this paper. The security parameters and security levels can be reflected by node quality. Second, the metric should be able to depict the heterogeneity of nodes in different sub mesh networks. The sub networks are divided into two kinds of network, slotted network and no-slotted network. Based on the QoS and security requirements, a framework of metric for HWMN is first present in this paper. According to the framework, a novel metric, busyness and load adjusted ETX, named as BLETX is then proposed. BLETX utilizes degree of busyness and load of node to describe node quality and ETX to depict link quality. The security and the abnormal of a malicious node can be reflected by node quality. Simulation results show that BLETX is suitable for both kinds of sub networks, and capacity of sub networks can be improved comparing with that only considering path quality, such as ETX.

Keywords: Heterogeneous Wireless Mesh Network; Routing Metric; Node Quality; Link Quality

1 Introduction

Along with the development of wireless communication technology, a lot of technologies emerge, such as IEEE 802.16 (WiMAX) [1], IEEE 802.15.3 (UWB), IEEE 802.11, IEEE 802.15.4 (ZigBee) and so on. The original wireless mesh network employing single communication technology, has improved into a highly integrated, robust and high bandwidth network: heterogeneous wireless mesh network (HWMN), which is composing of several kinds of multi-hop networks such as

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WiMAX and WiFi. Define the routing metric of HWMN is a main problem for the QoS and security.

First adopted routing metric is minimal hop count which is used for ad hoc networks. This method may have poor performance because the shorter path may have poor link qualities, which leads to poor throughput [2].

Then ETX method which calculates the expected transmission count of the packet on the link is proposed by Jitendra Padhye in [3]. The ETX metric avoids the problem of self-interference, and reduces the overhead greatly by the employ of broadcast probes. Many ETX-based routing metrics are proposed, such as WCETT, mETX, MIC and [4].

The heterogeneous wireless mesh network such as WiFi/WiMAX network has been studied in some literatures [5] [6]. A loosely cooperation is often designed by a coordinate MAC layer which could e effectively allow fast switching between different RATs which is also transparent to the upper layer [7]. In [8], the author introduces a throughput-efficiency optimal distributed data subframe scheduling scheme in WiMAX mesh networks.

Based on the shortcoming of metrics before and the need of a metric for HWMN, a framework of metric for heterogeneous wireless mesh network is first present in this paper. The framework models metric for HWMN into two parts: node quality and link quality. Furthermore, the framework gives the suggestion of depicting the heterogeneity of nodes in different sub mesh networks, by means of classifying networks into slotted networks and no-slotted networks, and calculating node quality separately according to corresponding strategy. Then a common metric for HWMN, busyness and load (BL) adjusted ETX, named as BLETX, is proposed. BLETX utilizes busyness and load of node to represent node quality, ETX to depict link quality. Simulation results show that BLETX is suitable for all sub networks. Capacity of sub networks are all improved comparing with that only considering path quality.

The main contributions of this paper are as follows: Analysis of routing metric for HWMN; Propose a framework of routing metric for HWMN; A new routing metric named BLETX is proposed which considers both the link quality and node quality for HWMN; Performance of BLETX metric is verified by NS2.

2 Motivation

2.1 Node quality and link quality for metric

Routing algorithm utilizes metric to judge which path has the best quality. Path is composing of nodes and links along it. Therefore, to reflect path quality more accurately, metric should take both node quality and link quality into account. We will take an example to represent the importance of considering node quality.

Assume the routing metric is ETX (Expected Transmission Count) [2], which is defined as the expected number of transmission, including retransmissions. We assume p_f and p_r denote the forward and reverse direction loss probabilities respectively, p is the probability of packet loss, and $s(k)$ defines as the probability that a packet is successfully transmitted after k attempts.

As the $k-1$ attempts before are failed and the k^{th} attempt successes, the expected number of transmission (ETX) is:

$$ETX = \sum_{k=1}^{\infty} k * s(k) = \frac{1}{(1-p_f)*(1-p_r)} = \frac{1}{1-p}. \quad (1)$$

Routing algorithm will choose the path with the lowest accumulative ETX. Now let's focus on the calculation of ETX. We can conclude that the ability of ETX to characterize the path quality is limited by the capacity of p_f and p_r. p_f and p_r denote the forward and reverse direction link loss probabilities, which mainly characterize the link quality. Although ETX is a very popular metric for wireless mesh network, it does not consider node quality. The disadvantage would be shown in Fig. 1.

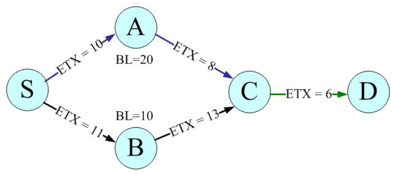


Fig. 1: Disadvantage of ETT

The Source node S has two paths routing to the Destination node D, which are S, A, C, D (SACD) and S, B, C, D (SBCD). Using ETX metric, the routing protocol will select path SACD as the cumulative ETX is 24 which is lower than that of SBCD's 30. However, the situation would be very different if considering node quality. Due to other nodes' interference and competition, BL of node A is much larger than that of B (other nodes' BLs can be ignored for the two paths share them). If considering node quality, routing protocol would select the other path, because the total quality of path SACD is 44, while that of path SBCD is 40.

From the scenario above, it can be concluded that routing metric should take both node quality and link quality into account, to reflect path quality more accurately.

2.2 Metric for HWMN

Metric should take both node quality and link quality into account as analysis above. Link quality for each sub mesh network of HWMN can be calculated according to same strategy. However, node quality should be computed by different strategies. This is because of working schemes of different networks are not same. For example, 802.11 mesh network is based on competition. Nodes in 802.11 mesh network need to compete transmission opportunities with other nodes.

The method adopted by 802.11 mesh network can not be utilized for slotted networks, such as WiMAX mesh network. WiMAX physical layer divide time into slots. Nodes in WiMAX network negotiate data transmission in control sub frame, which results as several slots in data sub frame for the transmission. Slots in data sub frame can be classified into available slots and unavailable slots. Available slots can be occupied to transmit packets, while unavailable slots have already been allocated to nodes for transmission. Therefore, without the concept of competition, node quality of such network could be calculated as available slots num divided by total slots num. The calculation could also be other forms which depend on specific strategy.

According to the analysis above, to depict the heterogeneity of each sub networks of HWMN, we should calculate node quality separately according to the characteristic of each network.

3 Framework of Routing Metric for HWMN and the BLETX Metric

3.1 Framework of metric for HWMN

As analysis above, in order to depict path quality of heterogeneous wireless mesh network more accurately, metric for HWMN should take two factors into account, which are node quality and link quality, denoted as NQ and LQ. The sub-network of HWMN could be modeled as, in which N and L are respectively the set of all the nodes and all the links in the sub-network. A path in the sub network can be modeled as $P = (N' \subseteq N, L' \subseteq L)$. N' is the set of nodes along the path, while L' is the set of links along the path. A framework of the path metric for HWMN would be present in formula 2, in which $\alpha + \beta = 1, 0 \leq \alpha \leq 1, 0 \leq \beta \leq 1$.

$$pmetric_{HWMN} = \alpha \cdot NQ_P + \beta \cdot LQ_P. \tag{2}$$

In the formula 2, NQ_P represents sum value of NQs in a routing path in the sub network, which can be calculated as,

$$NQ_P = \sum_{n \in P, N'} NQ_n. \tag{3}$$

While LQ_P reflects sum value of LQs in the routing path in the sub-network, which can be calculated as,

$$LQ_P = \sum_{l \in P, N'} LQ_l. \tag{4}$$

$pmetric_{HWMN}$ considers not only node quality but also link quality of a path. Now consider the path P, as shown in Figure 2. For the path, we define the node initializing routing request and data transmission as Source node, and the end node of data transmission as Destination node. A link in P has two end points, which can be named as starting point and end point of the link. For example, node i-1 is the starting point of link i, while node i is the end point of link i. Starting point transmits data packets to its link, while end point receives data packets from its link. Without consideration of Source node, we can map a link l and its end point n into one entry nl. Then we can define $P = Source + N''L'$, in which $N'' = N' - Source$, $N''L'$ is the set of mapped entry nl. Then $pmetric_{HWMN}$ can be calculated as formula 5:

$$pmetric_{HWMN} = \alpha \cdot NQ_{Source} + \sum_{nl \in N''L'} (\alpha \cdot NQ_{nl} + \beta \cdot LQ_{nl}). \tag{5}$$

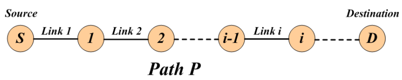


Fig. 2: Mapping of link and its end point

Any candidate path of a routing decision from a node has the same source node, so there is no need to calculate NQ_{Source}. Then $metric_{HWMN}$ can be computed as formula 6, in which $nl \in N''L'$.

$$metric_{HWMN} = \alpha \cdot NQ_{nl} + \beta \cdot LQ_{nl}. \tag{6}$$

To calculate NQ for different sub mesh network, different strategy should be adopted. We categorize networks into two kinds in this paper: slotted networks and no-slotted networks. WiMAX mesh network and UWB mesh networks both belong to slotted networks; while 802.11 mesh networks belongs to no-slotted networks. This kind of category can facilitate depicting heterogeneity of each network. Furthermore, the category can also be extended according to specific need.

3.2 BLETX: busyness and load adjusted ETX

Based on the framework of metric for HWMN, a novel metric, Busyness and Load (BL) adjusted ETX, named as BLETX is proposed in this section. Calculation is divided into two parts: BL and ETX. To compute the degree of busyness and load of node in sub network, we define BL as formula 7 in slotted networks and formula 8 in no-slotted networks.

$$BL_S = \frac{available\ slots}{total\ slots}, \tag{7}$$

$$BL_{US} = \frac{responded\ times}{unit\ time}. \tag{8}$$

The calculation of BL in formula 7 and 8 only represents node quality for a certain time point, which could not depict the node quality for a time quantum. We employ a tunable parameter subject $\gamma(0 \leq \gamma \leq 1)$ to compute the BL as shown in formula 9.

$$BL = \gamma \cdot BL + (1 - \gamma) \cdot BL'. \tag{9}$$

BL in the right denotes the original BL, while BL' is the newest simple BL we get. Note that each time node has the chance to work it will update BL. If the node is abnormal, the BL' will change in anomalous values. To compute ETX according to equation 1, we need to know the forward and reverse direction loss probabilities (p_f and p_r). The values of p_f and p_r can be estimated by using the broadcast packet technique. In summary, each node periodically (once per second) sends out a broadcast probe packet. Nodes track the number of probes received from each neighbor during a sliding time window (ten seconds) and includes this information in their own probes. Nodes can calculate p_r directly from the number of probes they receive from a neighbor in the time window, and they can use the information about themselves received in the last probe from a neighbor to calculate p_f. Then the bandwidth of each link is a firm value which is defined beforehand.

Now, BL and ETX are acquired, BL adjusted ETX can be calculated as formula 10, which is refined from formula 2.

$$BLETX = \alpha \cdot BL_{nl} + \beta \cdot ETX_{nl}. \tag{10}$$

Then utilizing formula 5 and 10, routing algorithm could select a path with best quality.

4 Simulation and Results

Without loss of generality, two kinds of networks are verified, which are WiMAX mesh network and WiFi mesh network, representing networks based on time slots and contention.

4.1 Simulation scenarios

The simulation is based on NS2. We simulate the parameters of (α, β) changing influence of BLETX in WiMAX and WiFi. The parameter $(1, 0)$ means the metrics of ETX.

There are 20 nodes in the scenarios, we choose one as the base station node randomly in WiMAX scenarioand the others are distributed in a $1000m * 1000m$ square area.

The transmission Range is set to 250 meters, and Carrier Sensing Range is set to 500 meters. We improve the UDP agent of NS2 for WiMAX, and create the interface between UDP agent and WiMAX module in order to WiMAX module can adjust the data generation rate of UDP.

4.2 Results of simulation

We implement a MAC module for the IEEE 802.16 mesh mode and utilize it to study system performance. The module consists of four logic parts, network controller, scheduling controller, data subframe scheduling controller, and data channel component. Utilizing NCFG and NENT control message, network controller is responsible for the network configuration, node entry, synchronization, etc. Scheduling controller handles the signaling channel contention, three-way handshaking and data subframe scheduling. Data subframe scheduling controller sets the request field, grant or confirm field properly in the MSH-DSCH message according to the scheduling result. Data channel component receives and transmits data packets in the allocated time slots. Node quality is calculated as formula 7. Configuration of WiMAX mesh network is as Table 1.

Simulation result of different combination (α, β) is shown in Figure 3(a). A proper assignment of (α, β) can promote network capacity greatly. When the coefficient of node quality values from 0.1 to 0.7, the average improvement of network capacity is 7.711%. However, the coefficient of node quality should be assigned carefully; otherwise, network capacity would be decreased, for example, (0.1, 0.9) and (0.0, 1.0).

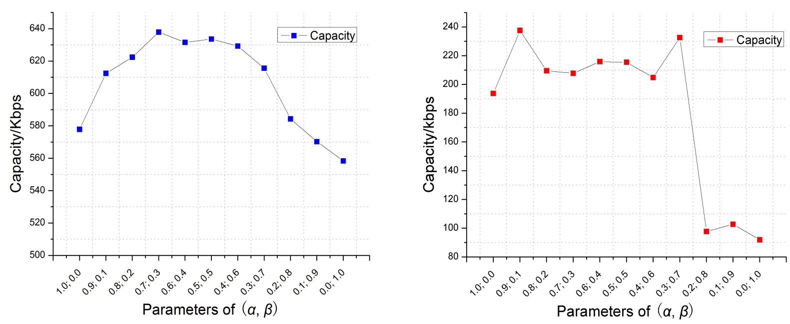
Mac 802.11 modules are modified to support node quality. Configuration of WiFi mesh network is similar with that in Table 1 and the differences are that TCP connection is 1, bandwidth is 11Mb and frequency band is 2.4GHz.

Simulation result of different combination (α, β) is shown in Figure 3(b). As WiMAX mesh network, (α, β) should also be carefully assigned to promote network capacity. When the coefficient of node quality values from 0.1 to 0.7, the average improvement of network capacity is 10.985%. However, the network capacity would be decreased if assigned (0.2, 0.8), (0.1, 0.9) and (0.0, 1.0).

From the simulation results, it can be concluded that BLETX improved network capacity greatly for both kinds of networks. However, the assignment of (0.2, 0.8), (0.1, 0.9) and (0.0,

Table 1: Configuration of WiMax mesh network

Entity	**Configuration**	
	Parameter	Value
Network Layer	Protocol	OLSR
Application	CBR/UDP ∗ 12	8Kbps
	TCP ∗ 3	200Kbps
Mac Layer	Queue Length	50
Physical Layer	Protocol	OFDM
	Bandwidth	5Mb
	Frequency Band	3.5GHz
	Frame Duration	8ms
	Scheduling Frame	1
	G_	0.25
	Control Subframe Ratio	30%
	Data Transmission Modulation	OFDM_16QAM_1_2
Propagation/Shadowing	pathlossExp_	2.7
	std_db_	4.0
Antenna/OmniAntenna	Gt_	18.0
	Gr_	18.0
Others	Simulation Time	500s
	Experiment Times	100



(a) Simulation result of WiMAX mesh network (b) Simulation result of WiFi mesh network

Fig. 3: Simulation result of WiMAX and WiFi mesh network

1.0) may decrease network capacity, which is mainly because of node quality takes most weight of routing metric. This would result in routing algorithm ignores link quality. Poor routing path would be selected, to induce lower network capacity. If a node is abnormal or dishonest, it can be detected by the values of BL_{nl}.

Therefore, (α, β) must be assigned carefully to maximize the capacity improvement and the empirical values of BL_{nl} can reflect the QoS and Security of wireless nodes on transmission paths. How to perform anomalous detection and assign (α, β) dynamically according to network situation is one of our future work.

5 Conclusion

A framework of metric for HWMN is proposed in this paper. The framework models metric for HWMN into two parts: node quality and link quality. The node quality can be used to reflect the QoS and secure of wireless nodes. Furthermore, the framework gives suggestion of depicting the heterogeneity of nodes in different sub mesh networks, by means of classifying networks into slotted networks and no-slotted networks, and calculating node quality separately according to corresponding strategy.

According to the framework, a novel metric, busyness and load adjusted ETX, named as BLETX is proposed. BLETX utilizes degree of busyness and load of node to describe node quality and ETX to depict link quality. Simulation results on WiFi and WiMAX networks show that BLETX is suitable for both sub networks. Capacity of sub networks are all improved comparing with that only considering path quality.

Studying strategies to depict node quality more accurately and detect the malicious nodes would be our future work.

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