An Optimized Routing Method for Neighborhood Area Networks

Jing Gao[1,a], Xuliang Guang[2], Peishang Gu[2], Qing Ren[2], Xin Song[2]

[1]School of Control Engineering Northeastern University at Qinhuangdao Hebei, China

[2]School of Computer Science and Engineering Northeastern University Liaoning, China

[a]summergj@126.com

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Abstract: The Smart Grid (SG) is the next generation of power systems. Designing a secure and reliable Smart Grid Communication Network (SGCN) is extremely critical to the realization of smart grid. The Neighbor Area Network (NAN) is in the middle of the SGCN and plays an important role as a bridge. Efficient communication is the premise of realizing a smart grid. The NAN routing algorithm is the core of its communication ability. In the routing algorithm, the routing mechanism directly determines the communication link to the node. The routing criteria play a key role in the routing process, and routing metrics directly affect the choice of communication link. This paper uses the optimized link state routing (OLSR) protocol in NS-3 to realize the performance of wireless mesh network (WMN) in smart grid automatic metering infrastructure (AMI). The simulation results show that, OLSR routing metrics need to be improved in order to meet the reliability requirements of AMI.

1. Introduction

With the explosive growth of the population and the rapid development of the economy, the existing power network can no longer meet the production and living needs of modern society. To solve the shortage of existing power, various countries are actively committed to researching the next generation of power networks. In accordance with the era of the promotion of green environmental protection and green energy conservation, the smart grid emerged. The smart grid is a new type of power grid system formed by integrating modern information systems into traditional energy networks, thus making the power grid more controllable and objective and solving the problems of low energy utilization and poor stability of traditional power grids [1].

The smart grid communication network (SGCN) consists of a wide area network (WAN), a neighbor area network (NAN) and a home area network (HAN) [2].

The NAN is in the middle of the SGCN, connecting the WAN and the HAN. It forms a communication platform between Smart Meters (SMs). SMs are responsible for the efficient measurement of electricity, and the distribution of data aggregation points (DAPS). Communication between DAPs acts a pivotal part in the entire smart grid communication network. NANs must meet user's different communication quality requirements. Therefore, it plays a key role in the SGCN [3].

The topology of an NAN is similar to that of mesh networks. Nodes in NANs are usually fixed in advance [4]. NANs are typically deployed in a diverse geographical environment with a large number of communication nodes. The NAN needs to cover all the smart meters and data aggregation nodes in the partition and to make the communication between those meters and nodes safe and reliable. In our paper, considering the characteristics of communication between nodes in NANs, we decided to adopt WMN structure as the communication structure of NANs [4].

Routing protocol plays a very important role in the quality of NAN communication [5]. The research on this subject has been extensively reviewed. There are several extant routing protocols for NANs [6]. Among these routing protocols, the Hybrid Wireless Mesh Protocol (HWMP) has received the most attention [7]. RPL supports multiple communication types and has sufficient security to meet different QoS requirements, so it is a primary routing protocol for NANs [6].

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DADR (Distributed Autonomous Depth First Routing) is designed to solve the problem of unreliable links and has been applied in japan [4]. HYDRO is a hybrid route that can be managed centrally and has great flexibility. There are many options for node routing, using DAG to deliver low-power node packets to border routes. Because of its high reliability and the use of multiple comparison routes, HYDRO can be used to monitor power quality and other applications. However, the question of whether HYDRO supports any particular application requires a variety of different costs to measure, and, more importantly, HYDRO does not consider data security during routing [6].

None of the above routing protocols can meet the high-quality communication requirements of the neighborhood network [4]. The three main factors considered in the design of routing protocols are the routing metric, the routing recovery mechanism and the routing mechanism. In this paper, we are concerned with the impact of routing metrics on the communication quality of NANs.

OLSR has performs better in a wireless mesh network than HWMP; therefore, OLSR can be an important option for routing protocols in a neighborhood network [8]. This paper will discuss the integration and optimization of OLSR to adapt to the smart grid neighbor network communication network.

This article focuses on OLSR. OLSR is a proactive routing protocol and usually uses Extended Transmission Count (ETX) as its routing metric. It has been applied in some experiments [8]. In order to meet the performance of smart grid, OLSR with different routing metrics is compared in NAN-based AMI ad hoc WMN on NS-3 network simulator [8].

The structure of this paper is as follows. Section II introduces several widely used routing metrics in WMN, such as ALM, ETX, HC and WCETT. In section III, a new routing metric, H-ETX (Hybrid ETX), is designed, which is based on ETX, interference, and channel switching delay. A simulation and performance evaluation of OLSR with HM, ETX and HC is presented in section IV. In the sixth part, we draw conclusions and discuss.

2. Classification of NANs by Routing Metrics

In this section, we focus on the impact of routing metrics on routing selection. We introduce and compare several routing metrics: ALM [9], ETX [10], ETT [11], WCETT [11] and HC [12], which can be used in mesh networks.

ALM mainly makes link selections based on space-time overhead and works in the link layer. The calculation formula of ALM is as follows [9]:

$$\text{ALM} = \left(O + \frac{B_t}{r}\right)\frac{1}{1-e_f} \tag{1}$$

where the e_f represents the frame error rate, it is calculated as:

$$e_f = \frac{M_n \times \frac{1}{p_n}}{R_{max}} \tag{2}$$

where the o is a header overhead, and B_t is a constant with a value 8192. The r is transmission rate, M_n is the number of MAC layer retransmissions by node n, and n is the number of retransmissions of node n. R_{max} is the maximum number of packet retransmissions.

Considering the complexity of the wireless network environment, the ETX value is proposed to improve its metric mechanism. The ETX value between a pair of nodes represents a predicted value of the number of transmissions required for a successful wireless data transmission between a pair of nodes, including the number of retransmissions. ETX is based on the working principle of bidirectional data transfer rate, which enables it to directly reflect the current state of network throughput, thus providing a reliable basis for path selection. The ETX calculation formula is as follows [10]:

$$\text{ETX} = \frac{1}{d_f * d_r} \tag{3}$$

where forward transmission rate d_f indicates the probability that data is successfully transmitted from the link source node to the link peer node, and reverse transmission rate d_r indicates the probability that the link source node successfully receives the response information from the link peer node.

ETX selects a path with throughput advantage, but the measurement mechanism does not reflect the busy degree of the measured path. Busy paths may cause delayed transmission of broadcast frames, but there will be no change in other parameters. This makes it possible for the metric mechanism to select a link with a higher load in a network that is sensitive to hidden terminal problems. In this case, the nodes in the link may rarely get the chance to send broadcast frames, thus affecting the performance of the network.

Based on ETX, the packet size *S* and the channel bandwidth *B* of the link are included in the calculation of the link cost to obtain ETT [11]:

$$\text{ETT} = \text{ETX} \times \frac{S}{B} \tag{4}$$

In multichannel wireless mesh networks, besides channel bandwidth and data transmission rate, channel diversity also has a very high utilization value in the measurement of path cost. For a system using multiple channels for data transmission, the sum of the time taken for data transmission on all the same frequency channels on one transmission path can be estimated according to equation (5):

$$Y_j = \sum_{link\ l\ on\ channel\ j} ETT_l,\ 1 \le j \le k \tag{5}$$

where *k* is the number of channels. When the factors of data transmission rate, channel bandwidth and channel diversity are considered together, the following equation can be used for path measurement [11]:

$$\text{WCETT} = (1-\phi) * \sum_{i=1}^{n} ETT_i + \phi * \max_{1 \le j \le k} Y_j \tag{6}$$

where ϕ represents an adjustable factor that takes a value within the interval [0,1]. The disadvantage of WCETT criterion is that when the route length is long, its scale estimation is not accurate.

HC (Hop Count) is a classical routing metric, which calculates the path based on the number of routes between source and destination [12]. The selection of routing metrics is a top priority in routing design [4].

3. New Routing Metric of OLSR

In this part, we first introduce the importance of designing a new routing metric for the neighborhood network. Then, we design a new metric for OLSR, Hybrid ETX (H-ETX).

3.1 Reasons for Designing New routing Metrics

In wireless mesh networks, a high-performance algorithm is one of the key factors to ensure an improvement in the efficiency and quality of service in a communication network, and the routing metric is the basis on which to determine the performance of the routing algorithm. OLSR's default routing metric is HC, which does not consider the channel quality problem and has difficulty meeting the network capacity and transmission performance requirements of wireless mesh networks.

Because ETX has very good performance in static or less changing topology networks, more experiments use ETX as the OLSR routing metric. However, ETX has two shortcomings: First, ETX does not directly consider the link speed and node load. Second, ETX does not consider the interference problem (namely, the intra-stream interference problem) when using the same channel to transmit. The interference factor is a problem that cannot be ignored in any communication system. It directly affects the reliability of data transmission.

ETX mainly considers packet loss rate and throughput. The communication environment of NANS is complex, so other factors that may affect the link quality should also be considered when routing. In an NAN environment with high communication quality requirements, channel interference is also a factor that cannot be ignored. We also use MRMC (Multi-Radio and Multi-Channel) technology to improve the throughput in NANs. Therefore, based on ETX, a more scientific calculation model of path data transmission cost is realized by adding interference measurement factors and channel switching overhead to the measurement model.

3.2 New Metric of OLSR: H-ETX

In this section, we design a new routing metric for OLSR: H-ETX. The calculation formula is as follows (7). H-ETX consists of three parts: ETX, the interference and the channel switching delay.

$$\text{H}-\text{ETX}=(1-\beta)\times\frac{ETX}{IR_i}+\beta\times CSC_i \tag{7}$$

where β represents a weight that takes a value within the interval [0,1], i is the link between two nodes (μ and v), and IR_i represents the interference rate. The calculation is as follows (8). CSC_i represents the channel switching delay, the formula as (11) [13].

$$IRi(\mu)=\frac{SINR_i(\mu)}{SNR_i(\mu)} \tag{8}$$

$$SNRi(\mu)=\frac{p_\mu(v)}{N} \tag{9}$$

$$SINRi(\mu)=\frac{p_\mu(v)}{N+\sum_{w\in\eta(\mu)-v}\tau(w)\,p_\mu(w)} \tag{10}$$

where N represents background noise in the current wireless environment. $\eta(\mu)$ represents a collection of nodes within the listening range of the node. $\tau(w)$ is used to represent the normalized data flow average generation rate of node w during the cycle time [4]. $p_\mu(v)$ represents the signal strength of node μ received by node v [4]. $p_\mu(w)$ represents the signal strength of node μ received by node w [4]. In the end, the interference ratio of the link from μ to v is the smaller one between $IRi(\mu)$ and $IRi(v)$ [4]. IR_i is calculated as :

$$IR_i=min(IRi(\mu),IRi(v)) \tag{11}$$

CSC_i is defined as [13]:

$$CSC_i=\begin{cases} w_1, & CH(pre(i))\neq CH(i) \\ 0, & CH(pre(i))\neq CH(i) \end{cases} \quad w_i\geq 0 \tag{12}$$

where i represents the node i. $CH(i)$ represents the channel of node i. $CH(pre(i))$ represents the previous channel of node i.

4. Simulation

In this simulation, we test three different routing metrics (H-ETX, ETX, HC) of OLSR by simulating the actual communication environment of the neighborhood network.

4.1 Simulation Setup

The role of Hello packets in OLSR protocol is link detection and neighbor discovery. In this paper, the HELLO message is used as the probe packet to calculate ETX by calculating the packet reception rates in the forward and reverse directions of the HELLO packet. When the ETX value between the local node and the neighbor node is obtained, the interference factor IR where the route is located is further calculated, and whether channel switching is performed before and after the route is judged.

4.2 Performance metric

The simulation hardware platform is VMware Workstation Pro, the software platform is the Ubuntu 16.04.3 operating system and NS3 (Network Simulator 3), and the NS3 version is 3.24.1. The environment used in all the simulations is described in table 1

Table 1. Simulation Parameters

Parameters	Parameter Value	Description of Parameter
WiFi Standard	802.11 b	WiFi Standard
m_nIfaces	2	Number of interfaces
m_totalTime	240 s	Simulation time
m_packetSize	1024	Packet size
m_step	50	Interval between nodes
m_packetInterval	0.1 s	Packet transmission interval
Numbers of nodes	3×3~3×20	Number of nodes
Tx power	16 dBm	Transmit power
phyMode	DsssRate1 Mbps	Physical layer transmission rate
Log-distance path loss	Exponent : 2.7	Loss model
Channel Number	2	Number of channels

As shown in Table 1, we use Mesh topologies for simulation: 3×*N* (*N* represents an integer from 3 to 20). It is particularly important that we use the loss model in the simulation. We use the log-distance path loss propagation model in this simulation.

For all tested protocols, the figures of merit considered are shown in Figure 2:

Table 2. Figures of Merit

Parameters	Description of Parameters
Average end-to-end delay(ETE)	The time required for a message to travel from one port to another
Average packet delivery Fraction	The ratio of accepted packets to transmitted packets
Average throughput	The number of bits that can be transmitted per second
Average packet loss ratio	The ratio of lost packets to transmitted data groups

4.3 Results & Discussion

After several tests, the comparison is made between the new routing metric H-ETX, ETX and HC, and the importance of the routing metric in path selection can be observed. In Figure 1, the result of the PDF is plotted. On average, OLSR with H-ETX still has a higher PDF than OLSR with ETX and HC with the increase in the nodes.

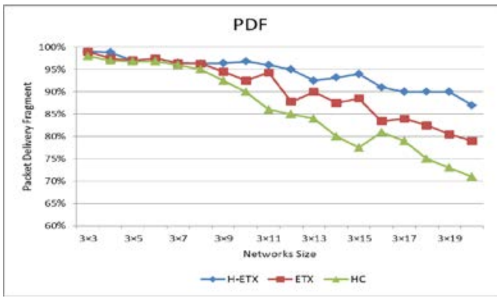

Fig.1. Average packet delivery Fraction

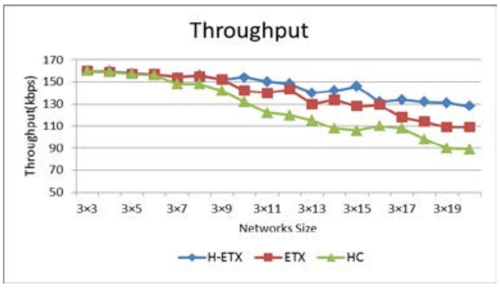

Fig.2. Throughput

The evolution of the throughput is presented in Figure 2. Checking the results, in smaller grids (less than 3×8), there is little difference in throughput using three different routing metrics, while in larger grids OLSR with H-ETX performs the best. Compared to OLSR with HC, OLSR with ETX improves performance by 12.5 %, and OLSR with H-ETX improves performance by 25 %.

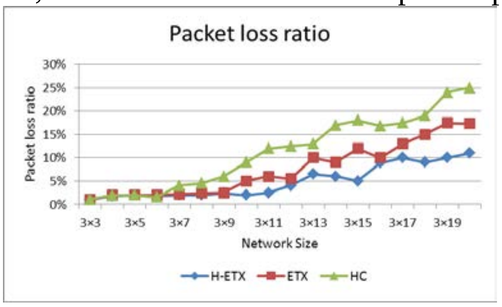

Fig.3. Average packet loss ratio

Figure 3 shows the difference in packet loss rate by using different routing metrics. It can be seen that OLSR with H-ETX has a very superior performance in terms of packet loss ratio relative to OLSR with ETX and HC. Its performance has been improved by approximately 30 % on average.

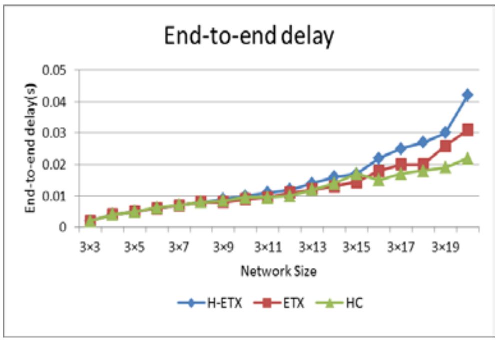

Fig.4. End-to-end delay

Figure 4 shows the difference in ETE by using different routing metrics. From the graph, we can observe that OLSR with H-ETX has almost no change in end-to-end delay compared with OLSR with ETX. When grids are small, there is almost no difference. In larger grids (larger than 3×14), OLSR with H-ETX obtains larger delays than OLSR with ETX and HC. In this respect, I need to do more research to determine the reason.

The experimental results show that OLSR with H-ETX has better performance than OLSR with other routing metrics as a whole, especially in terms of packet loss rate. PDF and throughput have been improved to varying degrees, but the ETE has not improved. In the next experiment, we will spend more time studying the relationship between routing metrics and ETE.

5. Conclusion

In this paper, we introduce a new routing metric for OLSR. We test three different routing metrics of OLSR by simulating the actual communication environment of the neighborhood network. OLSR with H-ETX combines three factors: the throughput, link interference and delay caused by channel switching during packet transmission, making it closer to the actual communication environment of NANs. We do experiments to verify the network performance of OLSR using three different routing metrics (H-ETX, HC, ETX). When routing with new routing metrics, network performance is generally improved. The performance index of average packet loss rate is obviously improved. As explained in the Results & Discussion, different metrics are the reason for improving routing performance. According to the experimental results, the network delay has not improved, and our next work will focus on it.

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