Service Priority based Reliable Routing Path Select Method in Smart Grid Communication Network

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Abstract

The new challenges and schemes for the Smart Grid require high reliable transmission technologies to support various types of electrical services and applications. This paper concentrates the degree of importance of services and tries to allocate more important service to more reliable network routing path to deliver the key instructions in the Smart Grid communication networks. Pareto probability distribution is used to weight the reliability of IP-based router path. In order to definition the relationship of service and reliability of router path, we devise a mapping and optimal function is presented to access. An optimal method is used for adapting to find the appropriate value to match the objective function. Finally, we validate the proposed algorithms by experiments. The simulation results show that the proposed algorithm outperforms the random routing algorithms.

Keywords: *Smart Grid communication, optimization, information entropy, pareto distribution.*

1. Introduction

Smart Grid, an emerging next generation electric power systems that integrates power infrastructures with information and communication technologies, is considering as a promising solution in its intelligence for energy crisis that we have to be faced [1]. One key feature of the Smart Grid is the integration of two-way, high-speed, reliable and secure data communication networks to manage the complex electric power systems effectively and intelligently [2]. The concept of Energy Internet [3] has been proposed to envision an exciting prospect of the future energy utilization paradigm throughout the energy generation, usage, transmission, and distribution phases. Smart Grid communication network, the essential components of Smart Grid, is responsible for data communication and information transmission [4]. Because the communication networks delivery almost every piece of messages of electric power system, many particular requirements are called for than the general communication network, such as different interface of AMI, latency stringent, nearly real-time data collection, track energy consumption, all kinds of applications and so on [5]. There are many challenges involved in the Smart Grid communication.

As the power energy generate, transmit and distribute simultaneously and green energy such as wind, solar, geothermal for electric utility [6], smart grid communication is undertaking new challenges and new schemes. In smart grid communication, many nearly real-time AMI data need be send to the control center or dispatching station in order to log the user bill of electric power [5]. Large number of electric meter data and multimedia data can deteriorate "the last mail" communication media, such as Power Line Communication [7]. Efficient use bandwidth is more concerned. Wireless network should be the option for the smart gird communication [8], by the reason of economical factor. However, wireless network has its unreliable drawbacks. Distributed generations require the scalable communication network, such as Wi-Fi, Ad Hoc network and ZigBee [9]. When many type of communication technology comes, reliable routing path is next question. Another new scheme is Demand Side Management. Peak Power Dissipation and Peak and Valley Price should be encouraged from our EMS. Because of heavy damage of outage, the communication network should highlight the most important services of electric utility. As the communication network may be broken down partially, N-1 principle applies to communication network. Therefore, in the multiple networks, we should put the most important electric power service on the more reliable communication networks to avoid the failure of key instructions, if it has sufficient bandwidths to supply.

There have been some works on the architecture for the Smart Grid communication. Three communication architectures have been proposed in a distributed way [10], IP-based architecture, Power Line Communication (PLC) architecture and wireless architecture. Because PLC architecture has low-speed shortcoming, Aggarwal *et al*. came up with the solution which is an IP-based network built on optic fibers in the Smart Grid communication. Two main reasons is that the IP-based network as the backbone of Smart Grid communication network can make use of emerging new technologies independent of service and that optical fibers can easily support the speed of several hundred gigabits per second over the long term. The Smart Grid communication depends upon the fast and free exchange of data between components, as the Cisco System Co. has presented [11]. The mathematical models are explored for communication architecture in Smart Grid communication and manifested that optical fiber is needed as the communication media for Smart Grid [10]. In this architecture, reliable network router path is prerequisite to delivery packets effectively and successfully. The poor communication network often suffers the network congestion to drop packet and more retransmission count that aggravate network congestion. Some crucial data and information should have the more reliable transmission possibility. The neighborhood area network (NAN), building area network (BAN), and home area network (HAN) for the lower distribution network are proposed to build the Smart Grid architecture [12].

In the electric power system, the crucial services have the top priorities for the reasons of the key instruction should be delivery in most reliable routing path instantaneously. The motivation is that we put the more important service on the more reliable routing path to reduce the average the package loss and retransmission. We the centralizes degree of importance of services and tries to allocate more significant service to more reliable network path to avoid network congestion in the Smart Grid communication networks.

In brief, this paper makes the following contributions to the field of the Smart Grid communication. Firstly, we use the entropy-based algorithms to weigh the degree of services in the communication network and compare with the APH algorithm which is used for measure the degree of importance of service. Second, in order to computer the reliable routing path, we devise a mapping and use the RTT parameter of end-to-end to apply the optimal method to iteration. At last, we show the results of two algorithms via experiments.

The rest of this paper is organized as follows. In Section II we introduce the related work about the service definition and RTT probability distribution. In Section III, we propose the entropy-based algorithm to compute the degree of importance of services and construct the mapping functions which can help to select the reliable routing path. Simulation results are presented in Section IV. Finally, we conclude this paper in Section V.

2. Related Work

2.1 Service Definition

There are some works related to the degree of the importance of services in the Smart Grid communication network. Smart Grid need smart service management was declared [13]. It stressed the understanding the services in the new multi-vendor (cloud) world, but how to do is not clear. Zhao *et al*. [14] formulated the electric power communication service and risk importance degree. However, risk importance degree was its main purpose to deal with the evaluation and not described the degree of importance of services in detail. Deshpande *et al*. [15] detailed the Qos of service in Smart Grid communication and listed the requirement of service.They used a strict priority queue to sort priority of service.They assumed the value of services as the prerequisite, but how to computer the degree of importance of services is not introduced.
In this paper, according to [16], the communication network of electric power system can be divided into four types by the media and application. That is voice service, data service, video service and multimedia service. In the type of four, there are include several detailed types of services. For example, data service includes relay protection, data of dispatching automatization of power system, the data of market data of power market and online biding system. The voice of service includes the dispatching of telephone system, meeting of telephone and power production and management telephone and so on. Therefore, type of service we refer to is the detailed services. That means we refine the service which is mentioned in the standard. Further, we identify every type of detailed services which can be used to complete the application and business in the Smart Grid. Thus, in communication network, every type of services should have its weight.

2.2 RTT Probability Distribution

Although many works have been done about the reliability of IP-based network, there are some results about RTT to mention. Fujimoto *et al*. proposed that the Pareto distribution is most appropriate in 95–99.9% region of the cumulative distribution of packet transmission delays [17]. Zhang *et al*. came to the conclusion that the cumulative distribution function of end-to-end delay could indicate network load situation and the entire end-to-end delay belongs to the Pareto distribution [18]. Chen *et al.* [19]

proposed that unknown and variable time delay can cause instability and that exact prediction of RTT can improve greatly performance. RTT along a certain path in the Internet can be modeled by a shifted Gamma distribution. The long-range autocorrelation is the research result. In the paper, we use the result of the RTT distribution.

3. Model and Analysis

In this section, we use the algorithm based on the information entropy to weigh the degree of importance of services firstly. Then, we devise a mapping to consider the difference between the weight of service and the value of reliable path. In order to get the value of reliable path, Pareto distribution statistical parameters are used to indicate the reliability of end-to-end routing path. We use the optimal method to computer the parameter and select the more reliable paths to route packet in IP-based network.

3.1 Degree of Importance of Services

Entropy is an efficient method to measure the uncertainty associated with a random variable. Entropy is the measurement of degree of uncertainty. Certainly ranked system should have small entropy value than the completely random system. Here, we introduce the information entropy to evaluate the degree of importance of services. The several key properties are constructed to represent the impact of the service. Assuming that each type of service has n parameters (such as maxim transmission delay, transmission frequency, and bandwidth etc.) used to represent the properties of service. The properties include the specific the values related to the service of electric power system. The more information owned by the properties, the more significant proportion which the attributes should have in the entropy system. We use the properties relevant to the services to describe the service. For every detailed service could have different property values. Thus it contributes the matrix with the different detailed services as the rows and properties as the columns. The properties includes: service belong to domain which is formulated by the regulations in [16], channels which is required at least more than two channels to supply so as to assure the power supply business in the regulations. The probability, transmission delay, and bit error rate. Then we construct the service matrix, use information entropy method to differentiate the respective service degree.

Now, according to regulations, all the services are attributed into the one of the 4 domain, 21 detailed types of services. The first domain has top priority than the last domain. If we use the number of 1 stand for the first domain and 4 for the last domain, the first column value of matrix must be the number not more than 4. In an addition, we append the last property to the service matrix. The property aims to evaluate the grade roughly if this service is damaged in the electric utility. Obviously, the exact the number could not access in the actual electric utility and communication networks. In the paper, 10 levels are set. We use the number 10 stand for the most extent of damage and so on. Similarly, the last column value of matrix must be the number not more than 10. The algorithm of entropy-based is described as follow:

Select available services, $S=(S_1,S_2,\cdots S_n)$ as a matrix row. Select available properties, $P=(P_1,P_2,\cdots P_m)$ as a matrix column. Thus we can get the matrix which is has element value a_{ij} which is value of property of P_j in the service S_i .

Before using entropy method, the data need to be normalized to eliminate dimensional units of property. We can get b_{ij} using following: for property j , we have

$$\max a_{ij}=\max\{a_{1j},a_{2j},\cdots a_{nj}\} \quad (1)$$

$$\min a_{ij}=\min\{a_{1j},a_{2j},\cdots a_{nj}\} \quad (2)$$

$$\begin{cases} b_{ij}=\dfrac{a_{ij}-\min a_{ij}}{\max a_{ij}-\min a_{ij}} & j\in J_+ \\ b_{ij}=\dfrac{\max a_{ij}-a_{ij}}{\max a_{ij}-\min a_{ij}} & j\in J_- \end{cases} \quad (3)$$

J_+ has shown that this value of property increase may have positive effect to distinguish the importance of service while J_- has the negative effect. Thus, we can get matrix B which has element values b_{ij} .

This method based information entropy main idea is every property has the different information range. Naturally more information could be comprised in more informative range. The wide range of the value of b_{ij} should include more information than the narrow range, when i varies. And the more information of property means less entropy. Let the e_i represents the entropy value of service i , then $e_i=-\sum_{i=1}^{n}\left(b_{ij}/\sum_{j=1}^{m}b_{ij}\right)\cdot\log\left(b_{ij}/\sum_{j=1}^{m}b_{ij}\right) \quad (j=1,2,\cdots m)$

$$\text{If } b_{ij}=0, then\left(b_{ij}/\sum_{j=1}^{m}b_{ij}\right)\cdot\log\left(b_{ij}/\sum_{j=1}^{m}b_{ij}\right)=0 \quad (4)$$

Maximum entropy can achieve based every value of property is very close to others. When every ratio is equal, the entropy is maximum, $\max(e_i)=\log n$. We can get relative the important degree, just follow the steps that the algorithm 1 proposes.

Now, we can simply analyze the algorithm complexity. The complexity of based entropy service importance algorithms is not more than $O(m\cdot n)$ whether the normalization or entropy calculation. So we can say the complexity of algorithm is O ($m \cdot n$). Generally, because m is a constant positive number, in the most conditions, the complexity of algorithm is accepted as $O(k \cdot n)$ with the growth of n. So we can consider the $O(k \cdot n)$ as the linear complexity.

Algorithm 1: Entropy-based Algorithm

Definition:
Arr : The array to temporary data storage
$M_j = \max[a_{1j}, a_{2j}, \cdots a_{nj}]$ $j \in (1, 2, \cdots m)$
$m_j = \min[a_{1j}, a_{2j}, \cdots a_{nj}]$ $j \in (1, 2, \cdots m)$

Initial: computer M_j and m_j, follow (1) and (2), get result b_{ij}.

After the normalized the data, we can use matrix b_{ij} to calculate the entropy of i.

for all the service s_i **do**
    for all the property p_j **do**
        if b_{ij} or $\log b_{ij} = 0$
        then $b_{ij} = 0$
        else
        $e_i = e_i - [(b_{ij} / Arr[i]) \cdot \log(b_{ij} / Arr[i])]$;
        end if
    $j{+}{+}$;
    end for
$i{+}{+}$;
end for
Normalize e_i.

3.2 Devise a Mapping

In order to measure the difference of degree of importance of services and path reliability in a small scope, we devise a mapping to associate RTT probability parameter with the degree of importance of services. This mapping is differentiable for many times so as to apply deepest iteration to find the most suitable solution. Therefore, we can think of the exponential function. We could construct a map with two unknown variable some like inverse Gaussian distribution:

$$g(x, y) = 1 - \exp(-\frac{(x-k)^2}{2y}) \quad k \text{ is a constant.} \tag{5}$$

3.3 RTT Distribution Parameter

In the paper, we calculate the reliability of end-to-end path in the communication network by the RTT distribution. In the communication network, praeto distribution parameters are essential to solve this problem.

X assumes to praeto distribution, $X \sim Pareto(\theta, \alpha)$ from above the descriptions. That means x_i has cumulative distribution function $F(x)$, $\forall \theta > 0, \alpha > 0$

$$F(x) = \begin{cases} 1 - \left(\frac{\theta}{x}\right)^{\alpha} & x > \theta \\ 0 & x < \theta \end{cases}$$

Further,

$$E(x) = \frac{\alpha\theta}{\alpha - 1} \quad \alpha > 1 \text{ and } \theta > 0 \tag{6}$$

$$D(x) = \frac{\alpha\theta^2}{(\alpha-2)(\alpha-1)^2} \text{ and } \alpha > 2 \text{ and } \theta > 0 \tag{7}$$

In order to evaluate the variation of $E(x_i)$ because of the variation of θ and α, variable substitution can be used. Then, $E(x)$ can be replaced by y_i while $\sqrt{D(x)}$ can be replaced by z_i. Now we use the mapping which is use y_i and z_i as variable, service weight as a constant, the location of k in (4), to construct an expression to find the best value approximating service weight in the given variance. Thus, original expression changes into follow expression.

$$g(y_i, z_i) = 1 - \exp\left[-\frac{(y_i - w_s)^2}{2z_i^2}\right] \; w_s \text{ is service weight} \tag{8}$$

Then, optimal expression can be created by function $g(y_i, z_i)$ and some constraints.

Minimize $g(y_i, z_i)$

$$\text{S.T} \left\| y_i - w_s \right\|_L \le b_1 \text{ and } \left\| z_i \right\|_L \le b_2 \tag{9}$$

Obviously, this question is optimal question with constrains. Because the functions satisfy the convex characteristic with inequality constraints and inequality constraints satisfy affine characteristic, we adopt the interior-point methods to solve it. Logarithmic barrier function $\phi(y_i, z_i)$ [20] is used to eliminate the inequality constraint condition.

3.4 the More Reliable Path

Now, we have achieved the RTT distribute parameters which is close to the degree of importance of services.

We can get the RTT measurable average value $\{r_1, r_2, \cdots r_n\}$ for every path at the sometime, then more reliable path r_* as follow:

$$\inf \{ r_* | r_i - E(x) \} \; r_* \in r_i \tag{10}$$

The path is more reliable path which is related to the specific service. Apparently, we should select the value

r_* which is not exceed the $E(x)$ and most close to the $E(x)$ as the expressed in (10).

Whole procedure can be divided into three parts by and large. The first part, we use the algorithm 1, to get the degree of importance of services. The result has been sorted to prepare to construct the optimizing expression in next step. Second part, we use a greedy algorithm, algorithms 2, to get the $E(x)$ and $D(x)$ by the on-line iteration. Third part, we compute average value of RTT by measured value. Here, we 500 sampled value. Compare and select the largest value and not more than $E(x)$. This part can process in advance and off-line calculation partially.

Algorithm 2: A Greedy Get Parameters of RTT

Definition:
A[i] aims to store the value obtained by the entropy algorithm to represent the degree of importance of services.
$t^{(0)}$ represents the initial iteration t value, here, $t^{(0)} = 1$;
initial feasible solution $(y_0, z_0) = (1,1)$
μ indicates the iteration step, here, $\mu = 10$
ε represents the iteration stop threshold and tolerance
m represents the number of constraints
Input A[i], (y_0, z_0), ε
Output (y_i^*, z_i^*) as the $E(x_i)$, $\sqrt{D(x_i)}$ value related to service S_i
1: **for** all A[i] **do** Get the value of S_i,
2: **while** $((m/t) < \varepsilon)$ **do**
3: Construct the optimization expression as follow:
$\min tg(y_i, z_i) + \phi(y_i, z_i)$ without the constraints
4: Use Newton method to solve, that means another iteration, we can get $x^*(t)$ value.
5: $x = x^*(t)$;
6: $t = \mu t$;
7: end while
8: $i++$;
9: end for

We now analyze algorithm complexity. Actually, algorithm complexity heavily depends on the triple loops. The number of outmost loop is the number of services, that is $O(n)$. The logarithmic barrier method includes the interior iteration, the complexity of Newton method, and the exterior iteration. The accurate complexity remains resolved problem. But we can roughly estimate complexity of the barrier method. The complexity of interior loop is not more than $O(\varepsilon_i^{-2})$, ε_i is interior loop threshold, because of the convex property and no-sensitive to initial values [21]. For every heuristic search of exterior iteration, the number of iteration is just as $\mu t^{(0)}, \mu^2 t^{(0)} \cdots, \mu^k t^{(0)}$, and the last $\mu^k t^{(0)} \le \varepsilon$. From above, we can solve the number of iteration $k = \ln(m/t^{(0)}\varepsilon)/\ln\mu$. In this case, we can further simplify the $k = -r\ln(\varepsilon)$ as $\mu = 10, m = 4, t^{(0)} = 1$, and r is a constant. The complexity of a greedy algorithm is $O(n \cdot \varepsilon_i^{-2} \cdot \ln\varepsilon^{-1})$. Clearly, the complexity of algorithm is related to threshold which is as the iterative accuracy parameters.

4. Evaluation and Performance

In this section, we make the simulations to evaluate the performance of the proposed scheme. Primaryly we contrast the algorithms to the others algorithms which is used to weigh the degree of importance of services in electric power system [22]. As we use the optimization to get the solution, we have to test the performance of the iterations concerned the iterative time and iterative number. Finally, simulation results show that the proposed algorithm yields a reduction in terms of the average transmission delay. All algorithms are implemented by MATLAB (R2010b; MathWorks, Natick, MA, USA).Experiments were run on a Intel(R) Xeon(R) CPU E5420 @2.5 GHz, with 30 GB of memory and the Red Hat Enterprise Linux Server release 5.4 operation system.
Simulation 1: we simulate entropy-based algorithm and Analytic Hierarchy Process (AHP) which is representative computer the degree of importance of services algorithm. Because of the parameters of fuzz process has not been described in the Fuzzy Analytic Hierarchy Process (FAHP), we think about the APH algorithm [22]. APH method will be more efficient in the performance than the FAPH and be accordance with the FAPH in ranking the service. Related data about the APH algorithm can be traced in the thesis. The seven properties are the domain which is one of four, the number of backup channels, fault probability, delay of transmission, transmission rate, bit error rate and the level of damage. They are represented by $p_1 \cdots p_7$ orderly. Three type of services are the data related to Dispatching Automation 110KV,OA and Dispatching Statistical Report. The services matrix is shown as following table 1.

Table 1: Value of matrix

s	p_1	p_2	p_3	p_4	p_5	p_6	p_7
s1	1	8	0.1%	20ms	384kbit/s	10^{-6}	7
s2	3	4	1%	2000ms	10Mbit/s	10^{-4}	6
s3	2	4	1%	500ms	2048kbit/s	10^{-5}	3

Firstly, we follow the entropy-based algorithm to construct the matrix and normalize it. We select the three type of service, as the talbe1, computer the value. Because the entropy-based algorithm is smaller number has the higher the degree while the APH is the opposite, we use the $\log n/value$ to compare. The picture and graph as the fig 1. We can draw a conclusion that the two algorithms have the consistent with the rank of service. That is service1 is more important than service 2, and service 2 than service 3.

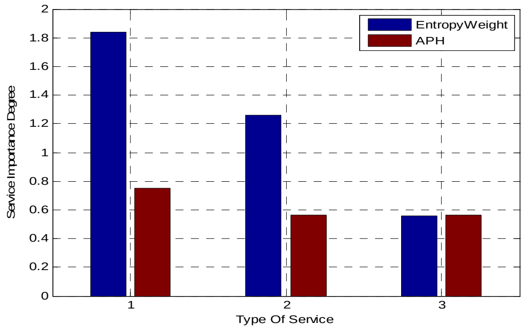

Fig 1. Service rank

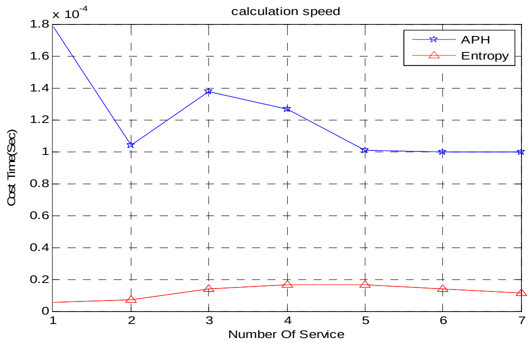

Fig 2. Efficiency of algorithms

Next, we evaluate the efficiency of the two algorithms by the cost time. The APH algorithm has to check the consistency of complementary matrix. However, it is strongly related to matrix order n. The more order the matrix has, the more time it cost for consistency. 4 order matrix costs more time and graph has a vertex beside the start time as fig 2 shown. As the revealed in the graph, entropy-based algorithm has the lower time overhead than the APH algorithm. Moreover, in contrast, entropy-based algorithm adapt to the dynamic, instantaneously computation for the rank of services than the APH algorithm.

Simulation 2: because of the optimization of algorithm 2, we should evaluate the performance of iteration. Iterative number and iterative time are pertinent. As the transmission constraint in the Smart Grid, the solve iteration is not possible to consume too long time to find the optimal solution. On the other hand, the stop criteria of iteration require some necessary precision to control in order to find optimal solution. Therefore, there is a tradeoff between the precision of criteria and the number of iteration. In this paper, we have selected the parameter, $t = 500$ and $\mu = 10$. We set the precision array [1 0.5 0.1 0.05 0.01 0.005 0.001 0.0005 0.0001] to test the iterations. At $w_2 = 0.8724$ the initial value [x, y] = [1, 0.5]. Results are visible as fig 3.

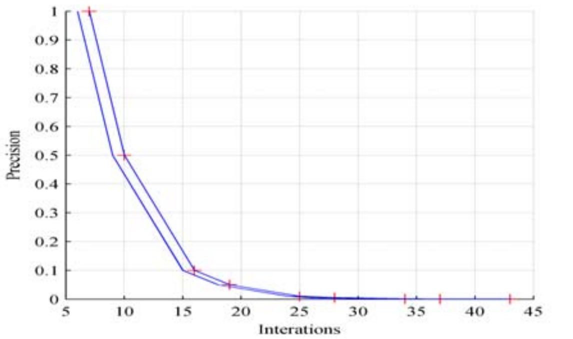

Fig 3. Iterative number and precision

As the graph has shown, the initial value is insensitive. At the precision 0.05, iteration is not more than 20.

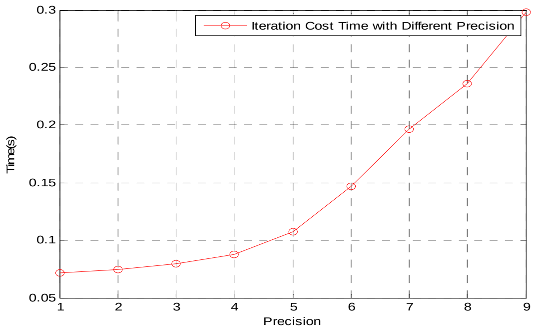

Fig 4. Iteration cost time

We select the 8 type of service contain domain 2 and domain 3 in dispatching data network. For precision array [1 0.5 0.1 0.05 0.01 0.005 0.001 0.0005 0.0001], iteration time costs as the fig 4. Iteration cost time is growth as the precision increment and it is main trend of graph. However, increasing amount is not linear.

Simulation 3: we select the Guangzhou power dispatching data network based on VPN technique. Because many type of service is between the substations, we simulated this in the NS2 [23].The experiment environment is Red Hat Enterprise Linux Server release 5.4 operation system. The trace file is used to record experiment data. As a data assemble center, many types of services is integrated the multiple managements system. We use the center as a data send source and several distribution substations as a data receive node. We randomly simulate the 8 routing path in VPN application.
As the bandwidth is enough available in now electric utility [24], so throughput is not necessary index. We now present the jitter index. Jitter is an important Qos factor in

evaluation to network. It is often used as a measure of the variability over time of the packet latency across a network. Jitter is expressed as an average of the deviation from the network mean latency. A small jitter parameter manifests the more reliable network.

Jitter=(((recvtime(j)-sendtime(j))-(recvtime(i)-sendtime(i))) /(j-i) and j>i.

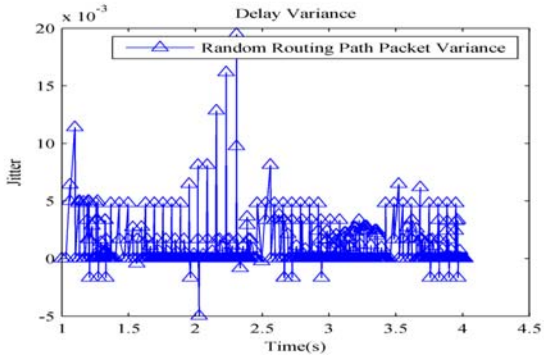

Fig 5(a). Jitter in random routing path

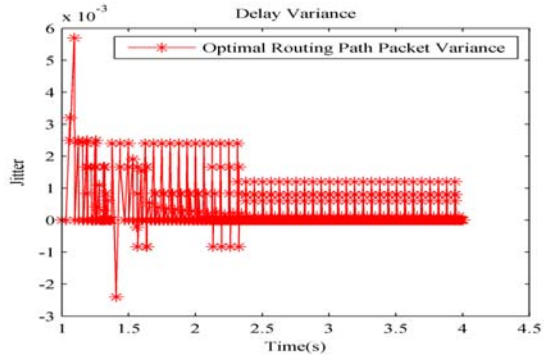

Fig 5(b). Jitter in optimal routing path

Fig 5 (a) shows the jitter of the random routing path. In the 4.0 seconds, we stop the send packet. Packet delay variance is not more than the ±0.02 with the 10Mb bandwidth and buffer queues 10.

Fig 5 (b) shows the jitter of reliable Dispatching Automation 110Kv application packet variation is not more than ±0.006 with the 10 Mb bandwidth and buffer queues 10.We select the center of dispatching data center, allocation 5 channel which is 2M for the three of service. We use our algorithm to evaluate the reliability of every routing path and allocate the service. We simulate the packet delivery and plot the jitter index in the random routing path and the optimal routing path. The experiment data have indicated that we can reduce jitter ratio about 60% for key services. The algorithms we proposed has the high efficiency in deal with the key services in the smart gird communication network.

4. Conclusions

In this paper, a novel scheme to combine the important services in the Smart Grid to reliable routing path is proposed in communication network in order to deliver key packets. In IP-based Smart Grid communication architecture, we use the RTT Pareto probability distribution to measure the reliability of routing path. For this purpose, we devise a mapping to construct the evaluation criterion between reliability and the degree of importance of services which is distinguish the different service in electric utilities. In addition, optimal method is used to find the suitable values which match the objective function approximately. Simulations results show that the proposed scheme can yield the better result than random routing path in Smart Grid communication network.

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