Taoshen LI, Zhihui GE, Hongyu ZHANG
Guangxi University

M/M/1 Solution for Gateway Scheduling in Wireless Mesh Networks

***Abstract**. Wireless Mesh Networks (WMNs) has become the important Internet infrastructure of next generation network, low-cost and convenient network connectivity is complimentary for end users. By deploying one router to connect the Internet directly as gateway and a few transient routers, WMNs can be constructed rapidly and efficiently. In the process of commercialization, how to allocate bandwidth reasonably and schedule high performance is still a knotty problem. To solve this, in this paper, from the perspective of a gateway, we discuss WMNs capacity and delay problem, and propose a queuing theory model M/M/1 for gateway scheduling scheme (QGSS) to apply the question of data flows scheduling of gateway and the number of gateways for deployment in WMNs. Results of the experimental simulation of QGSS are given to illustrate the proposed technique by Matlab2010a. The results show that we obtain a fair scheduling scheme and higher network resource utilization.*

Streszczenie:** Bezprzewodowe sieci kratowe (WMNs) mogą stać się najważniejszą infrastrukturą Internetu w sieciach nowej generacji, w których komunikacja przez tanią i wygodną sieć będzie bezpłatna dla końcowego użytkownika. Konstrukcja WMN może być efektywna i tania przez przyjęcie jako bramki jednego rutera dołączonego wprost do Internetu i kilku ruterów łączonych przejściowo. Wobec komercjalizacji, trudnymi problemami do rozwiązania są rozsądny podział pasma i wysokie parametry szeregowania. W opracowaniu zbadano przepustowość WMN i problem opóźnienia z punktu widzenia bramki. W schemacie szeregowania bramki (OGSS) przyjęto model przeszukania M/M/1. Badania zostały wykorzystane do określenia szeregowania przepływu danych przez bramkę i ilości bramek rozmieszczonych w WMN. Aby zilustrować zaproponowane rozwiązanie przeprowadzono symulację OGSS przy pomocy programu MatLab2010a. Wyniki pokazują, że otrzymano zadawalający schemat szeregowania i pomysłowe wykorzystanie sieci.* ***Rozwiązanie M/M/1 do szeregowania bramki w bezprzewodowych sieciach kratowych

Keywords: wireless mesh networks, gateway scheduling, queuing tiheory
Słowa kluczowe: Bezprzewodowe sieci kratowe, Szeregowanie bramki, Teoria przeszukiwania

Introduction

Internet technological revolutions have recently changed the communications. Wireless Mesh Network as typical representative of these revolutions has caused extensive concern. In campus, community, and Central Business District (CBD), even emergency response, where wired network is deployed expensive, or survivable networks is needed, Wireless Mesh Networks (WMNs) can be constructed, and provided high performance broadband wireless access. Relying on a core stationary router which access to the backbone network and other many transit routers, a huge coverage network can be built rapidly and low-cost. Other than the routing capability for gateway/ bridge functions as in a conventional wireless router, a mesh router contains additional routing functions to support mesh networking. With the widespread use of WMNs, the network increasingly concerned about the scheduling and delay1. In [2], they propose a max-min fairness solution in traditional wired networks, and it cannot be applied to WMNs directly, because it requires each channel has a fixed bandwidth capacity, which is not sure in wireless mesh environment where link bandwidth is changed dynamically, depending on link conditions and connectivity of nearby links. For end-to-end flows, which are frequent in WMNs, such solutions ignore the relationship among the flows from the same end-to-end flow3. In [4], they propose an algorithm for Max-Min capacity calculation, formulated in term of collision domains. But they ignored the collision in gateway area, that's a key problem for WMNs performance. About gateway scheduling, some researchers have studied about other area environment, such as [5], the paper analyzes performance of model media gateway controller for telephones model based on common open policy server which is a protocol defined in Internet Engineering Task Force to transport configuration requests and deliver the policies. The paper inspired us about gateway scheduling way in WMNs. In [6], they present simple exponential approximations to the transient behavior of the stable M/M/1 queue. Through experiment, they validate approximations are optimal in a least-squares sense, and they find the experiment to agree with exact results well. On congestion control and delay control, many studies have been carried out, they study a novel game theoretic incentive mechanism in paper [7-8], and they design problem for network congestion control in the context of users whose property is selfish that sending data through a single store and forward router.

The scenario is modeled as an M/M/1 queue model with each user aiming to optimize a trade-off between delay and capacity in a distributed manner.

In summary, most researchers have studied the congestion and delay in traditional wired internet, some of them use queue theory to analyze delay and throughput, but few of them considered the problem in WMNs scenario, in order to solve the scheduling and problem in WMNs using queuing theory, we propose this paper. This paper describes M/M/1 model of queuing theory application in WMNs and deducts a formula for computing data flow delay of gateway in WMNs, proposes a closer to actual situation method which can be used to design and determine the better WMNs structure and data flow delay and its performance is very helpful.

The rest of the paper is organized as follows. Section 2 discusses related M/M/1 model and its common calculation formula. Section 3 presents a framework to study the scheduling of gateway and proposes a scheme named QGSS by computing each flow delay using M/M/1 model for scheduling of gateway in WMNs in order to obtain fair scheduling. Section 4 validates our assumption and analysis through experiment. Section 5 concludes our paper and supposes future work.

M/M/1 Model Formula

Single-service queuing system M/M/1, which describes the information that arrives to obey Poisson distribution (i.e. exponential distribution), and the service process time also obeys Poisson distribution. There is only one attendant in the M/M/1 system, and infinite queue space (butter mechanism) and FIFO (first-in first-out) system. Figure 1 shows a single service attendant queue system.

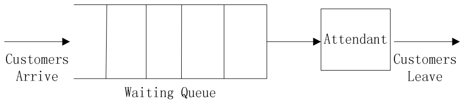

Fig. 1. Illustration of M/M/1 Queue

We assume that the number of customers as i+1 in system, so the system is in state i. When a new customer arrives, the system changes from state i to state i+1; or after receiving service a customer leave the service area, the system changes from state i to state i-1. System is in equilibrium, that is, the system is in a given state i, and the probability is no change as time elapses. Supposing P_i is the probability of the given state i, $E(N_i)$ is arrival rate in the average when the system in state i, so we use $E(N_i)P_i$ to describe the number of changes per unit time during the system changes its state from i to i+1 in the average; the change rate in the average from the state i to state i-1 is $P_i / E(t_{si})$. The formula $E(N_{i-1})P_{i-1} + P_{i+1} / E(t_{si+1})$ is state transition rate which transferred to state i (original from state i-1 and i+1) in the average. In which, $E(t_{si})$ is the average service time for the system is in state i.

In dynamic equilibrium, the average rate of transferring in state i should be equal to the average rate of transferring out state i, so you can create a series of equations. These equations are for the different system state, transferring in rate equal to transferring out.

State 0

(1) $$P_1 / E(t_{s1}) = E(N_0)P_0$$

State 1

(2) $$E(N_0)P_0 + P_2 / E(t_{s2}) = E(N_1)P_1 + P_1 / E(t_{s1})$$

State 2

(3) $$E(N_1)P_1 + P_3 / E(t_{s3}) = E(N_2)P_2 + P_2 / E(t_{s2})$$

State i

(4) $$E(N_{i-1})P_{i-1} + P_{i+1} / E(t_{si+1}) = E(N_i)P_i + P_i / E(t_{si})$$

We can obtain the result from the equation (1):

$$P_1 = E(N_0)E(t_{s1})P_0$$

And take P_1 into (2):

$$P_2 = E(N_0)E(N_1)E(t_{s1})E(t_{s2})P_0$$

So, the P_i can be obtained by analogy derivation:

(5) $$P_i = P_0 \prod_{k=0}^{i-1} E(N_k)E(t_{sk+1}) \cdots \quad i = 1,2,\cdots$$

Total probability equal to 1, so:

$$\sum_{i=0}^{\infty} P_i = 1$$

$$P_0 + \sum_{i=1}^{\infty} P_i = 1$$

Take (5) into P_i,

(6) $$P_0 = \frac{1}{1 + \sum_{i=1}^{\infty} \prod_{k=0}^{i-1} E(N_k)E(t_{sk+1})}$$

Framework and QGSS

In Wireless Mesh Networks, the data flows generated by each transient node and the gateway its own all converge at the gateway for accessing the Internet. At the gateway, all the traffic can be abstracted as single service attendant queue system named Q are waiting for service. The queue is composed of the flows E which are waiting for service and the flows S which are in service. We can be obtained from the figure 1.

(7) $$Q = W + S$$

E can represent the average relationship with the queue, so:

(8) $$E(Q) = E(W) + E(S)$$

The average length of the queue equals to the sum of the average number of flows which are waiting for service and which are serviced. So, the average time of the queue $E(t_Q)$ equals to the sum of the average time of flows $E(t_W)$ which are waiting for service and $E(t_S)$ which are serviced.

(9) $$E(t_Q) = E(t_W) + E(t_S)$$

At the gateway, we consider equipment utilization a key problem as the same as in the queuing theory, it expresses the frequency of the gateway devices, we use λ to repress:

(10) $$\lambda = E(N) \cdot E(t_S)$$

Where, λ is the device utilization within the average arrival number of customers at the gateway in service time, it is equal to the average arrival rate $E(N)$ multiplied by the average service time.

At the steady state, the number of waiting for service:

(11) $$E(W) = E(N)E(t_W)$$

The average length of the queue:

(12) $$E(Q) = E(N)E(t_Q)$$

We consider (9) by take (8) into (11):

(13) $$E(Q) = E(W) + \lambda$$

In M/M/1 queuing system,

$$E(N_i) = E(N) \quad i = 0,1,2,\cdots$$

$$E(t_{si}) = E(t_s) \quad i = 1,2,\cdots$$

Take two equations above into (6):

(14) $$P_0 = \frac{1}{1 + \sum_{i=1}^{\infty} \prod_{k=0}^{i-1} E(N)E(t_s)} = \frac{1}{1 + \sum_{i=1}^{\infty} \left[E(N)E(t_s) \right]^i} = \frac{1}{1 + \sum_{i=1}^{\infty} \lambda^i} = \frac{1}{1 + \frac{\lambda}{1-\lambda}} = 1 - \lambda$$

And take them into (5)

(15) $$P_k = P_0 \prod_{k=0}^{k-1} E(N)E(t_s) = (1-\lambda)\lambda^k$$

The number of the flows $E(Q)$ in the gateway:

(16) $$E(Q) = \sum_{i=0}^{\infty} iP_i = (1-\lambda)\sum_{i=0}^{\infty} i\lambda^i = (1-\lambda)\lambda \frac{\partial}{\partial\lambda} \sum_{i=0}^{\infty} i\lambda^i = (1-\lambda)\lambda \frac{\partial}{\partial\lambda}\left(\frac{1}{1-\lambda}\right) = (1-\lambda)\lambda \frac{1}{(1-\lambda)^2} = \frac{\lambda}{1-\lambda}$$

The average waiting flows number in the gateway:

(17) $$E(W) = E(Q) - \lambda = \frac{\lambda^2}{1-\lambda}$$

The average waiting time of the flows in the gateway:

(18) $$E(t_W) = \frac{E(W)}{E(N)} = \frac{\lambda}{1-\lambda} E(t_S)$$

To solve the problem about utilization and scheduling in the gateway, so we have to suppose to reduce the delay of flows in the gateway, through the equations above, we can obtain the equation for calculating delay for flows in the gateway:

(18) $$E(t_Q) = E(t_S) + \frac{\lambda}{1-\lambda} E(t_S) = \frac{E(t_S)}{1-\lambda}$$

It can be realized, as long as we know the device utilization and service time, we can obtain the queue size, average queue time and waiting time, provide a calculating basis for us next to solve the optimal problem.

Stochastic service system in the establishment of a mesh network queuing model, in order to make effective use of the model for Wireless Mesh Network configuration, we need solve the model for analysis. We determine the average delay value as the objective function, under throughput to meet certain conditions, to determine the optimal average value, and prompt the delay of each node to balance, maintaining a certain level of throughput increasing at the same time.

We use Marginal Analysis Method to and calculate and determine the relationship between the gateway and the delay in order to get the best network structure. The delay $E(t_Q)$ is as a function of the gateway G. So, that is the equation,

$$T(G)=E(t_Q)=E(t_W)+E(t_S)=E(W)\times P_W+E(S)\times P_S$$

$$=E(W)\times P_W+G\times E(t_S)\times P_S$$

$$=(1-\bar{P})\times E\times\lambda\times\overline{E(t_W)}\times P+\bar{P}\times E\times\lambda\times\overline{E(t_W)}\times P_W+G\times E(t_S)\times P_S$$

$$=(E\times\lambda\times\overline{E(t_W)}\times P_W)+(E(t_W)-\overline{E(t_W)})\times\bar{P}$$

$$\times(E\times\lambda\times P_W)+G\times E(t_S)\times P_S$$

Recording $A=E\times\lambda\times\overline{E(t_W)}\times P_W$, $B=E\times\lambda\times P_W$, $C=E(t_S)\times P_S$, A, B, C are independent constant value of the number of the gateways. We can obtain them from the statistics calculated. And $\overline{E(t_W)}$ is the waiting time of the flows on the average in gateway, $\bar{P}$ is the flows to gateway necessary waiting probability for gateway, that they are all related with the number of gateways, then, the equation can be rewritten as:

$$T(G)=A+(T_W(G)-\overline{E(t_W)})\times\bar{P}(G)\times B+G\times C$$

Assuming the optimal number of gateways as G^*. It makes the total delay $T(G)$ minimum. Due to the characteristic value of G^*minimum,

$$T(G^*)\le T(G^*-1) \text{ and } T(G^*)\le T(G^*+1)$$

$$A+(T_W(G^*)-\overline{E(t_W)})\times\bar{P}(G^*)\times B+G^*\times C$$

$$\le A+(T_W(G^*-1)-\overline{E(t_W)})\times\bar{P}(G^*-1)\times B+(G^*-1)\times C$$

$$A+(T_W(G^*)-\overline{E(t_W)})\times\bar{P}(G^*)\times B+G^*\times C$$

$$\le A+(T_W(G^*+1)-\overline{E(t_W)})\times\bar{P}(G^*+1)\times B+(G^*+1)\times C$$

Get the equation after simplification:

$$\bar{P}(G^*)\times(T_W(G^*-\overline{E(t_W)})-\bar{P}(G^*+1)\times(T_W(G^*+1)-\overline{E(t_W)})\le\frac{C}{B}$$

$$\le\bar{P}(G^*-1)\times(T_W(G^*-1)-\overline{E(t_W)})-\bar{P}(G^*)\times(T_W(G^*)-\overline{E(t_W)})$$

Turn to G = 0, 1, 2, 3… $\bar{P}(G^*)\times(T_W(G^*)-\overline{E(t_W)})$ values, and calculated difference for two adjacent values. Since $\frac{C}{B}$ is independent of G, it can be based on a range in which this reproach for G, the number of gateways for the optimal value.

Validation

We use Matlab2010a for the simulation of QGSS program in WMN, and basic scheduling results to improve the program for comparison. Figure 2 and Figure 3 shows the data transfer rate of 5.5 Mb / s and 11 Mb / s when the saturation throughput of the basic scheduling program results and improve results. Also shows data transfer rate in the 5.5 Mb / s and 11 Mb / s when the average packet delay of the simulation results and improve program results. It can be seen, calculated by the mathematical model of saturation throughput and average packet delay and throughput have been good application effect.

Conclusions

We can deal with relationship between time delay and gateway deployment well by using QGSS, it can be applied to scheduling, play a positive role, and enable the whole network throughput in steady state and gained further improved, the gateway internal details scheduling problem about queue model and optimization scheme will continue in the following study.

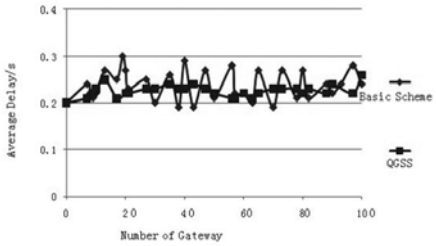

Fig.2. QGSS and Basic Scheme for Average Delay

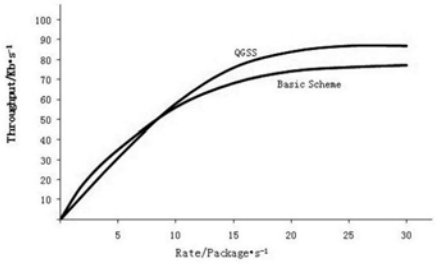

Fig.3. QGSS and Basic Scheme for Throughput

Acknowledgments

This work is supported by the National Natural Science Foundation of China under Grant No. 60963022; the Guangxi Ministry of Education Foundation (TLZ100714).

REFERENCES

[1] Akyildiz F., Wang X., Wang, Wireless mesh networks: a survey, Computer Networks Jour W.nal (Elsevier), 47(2005), No.4, 445-487

[2] Faffe J. M.. Bottleneck Flow Control, IEEE Transactions on Communications, 29(1981) , No,7 ,954-962.

[3] Li B., End-to-End Fair Bandwidth Allocation in Multi-hop Wireless AdHoc Networks, Proceedings of the 25th IEEE International Conference on Distributed Computing Systems, Columbus, Ohio, USA ,(2005), 471-480

[4] Aoun B., Boutaba R.. Max-Min Fair Capacity of Wireless Mesh Networks, Proceedings of the 2006 IEEE International Conference on Mobile Adhoc and Sensor Systems (MASS), Vancouver, BC , (2006),21-30

[5] Hajipour P., Amani N., Mostafaei F. S., Analysis of M/M/1 Queuing model of Reservation Management for Media Gateway Controller, Proceedings of the 12th International Conference on Advanced Communication Technology (ICACT), Phoenix Park, Korea, 2(2010),1371-1376.

[6] Bolot J. C., Udaya Shankar A., Optimal Least-Squares Approximations to the Transient Behavior of the Stable M/M/l Queue, IEEE Transactions on Communications, 43(1995) , No, 2/3/4 ,1293-1298.

[7] Gai Y., Liu H., Krishnamachari B., A Packet Dropping-Based Incentive Mechanism for M/M/1 Queues with Selfish Users, Proceedings of the IEEE Conference on Computer Communications(INFOCOM),Shanghai,China,(2011), 2687-2695

[8] Wu D., Negi R., Effective capacity: a wireless link model for support of quality of services, IEEE Transactions on Wireless Communication, 4(2003) , No, 2,630- 643

***Authors**: prof. Taoshen Li, School of Computer and Electronic Information in Guangxi University, 100 Daxue Road Nanning, P. R. China, E-mail: tshli@gzu.edu.cn; vice prof. Zhihui Ge, School of Computer and Electronic Information in Guangxi University dr inż. Jan Cichocki, , 100 Daxue Road Nanning, P. R. China, E-mail: gezhihui@foxmail.com; Hongyu Zhang, School of Computer and Electronic Information in Guangxi University, 100 Daxue Road Nanning, P. R. China, E-mail: hongyu86315@yahoo.com.cn*