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A Quality of Service Supported Time Division Multiple Access Slot Assignment Protocol with Cross Layer Design

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Abstract: A new distributed slot assignment protocol to minimize end-to-end delay for multi-hop service-MRSA (Multi-hop Relay Slot Assignment) is proposed in this study. This protocol adopts a new multi-hop relay reserve mechanism to establish a virtual pipeline connected the source and destination node before relaying the multi-hop service data packets. Modeling analysis and simulation results showed that the MRSA can still make the effective slot assignment and reduce the end-to-end delay when compared with traditional Time Division Multiple Access (TDMA) protocol even under heavy traffic load.

Key words: Time division multiple access, end-to-end delay, cross layer, five phase reserve protocol

INTRODUCTION

In recent years, the application of multi-hop TDMA based wireless Ad Hoc networks, such as wireless sensor networks and commercial mesh networks (802.11s), has gained considerable attention. This has prompted the development of TDMA based protocols. There are two main problems in TDMA based protocols. One is the allocation of the slots resource with no conflict and the other is the end-to-end delay for multi-hop service. In order to solve the problem of slots resource allocation, new protocols based TDMA were proposed by Parthasarathy and Gandhi (2004), Moscibroda and Wattenhofer (2005), Xu *et al.* (2006) and Hongyan and Valaee (2004). These new protocols provided a conflict-free slots allocation in the network taking advantage of spatial reuse. However, in the multi-hop wireless network, the traditional TDMA based protocol will always introduce large end-to-end delay. Methods proposed by Ramanathan and Lloyd (1993), Kodialam and Nandagopal (2003), Gandham *et al.* (2005) and Ergen and Varaiya (2005) designed schedules with minimum TDMA delay by finding schedules with minimum frame size. But these methods are not practical, because they will result in the reboot of networks. Protocols proposed by Djukic and Valaee (2009) use an iterative algorithm to find minimum length schedules which can optimize the min-max scheduling delay. And protocols proposed by Wang *et al.* (2010) providing coarse-grained end-to-end QoS support method for multi-hop applications.

In this study, a MRSA (Multi-hop Relay Slot Assignment) protocol based on FPRP (Five Phase Reserve Protocol) using the method of cross layer design had been proposed. The MRSA protocol can arrange and reserve the slot resource for every node on the route to reduce the end-to-end delay obviously for a multi-hop service with the cross layer information.

NETWORK AND TRANSMISSION MODEL

This research focused on the wireless networks used dynamic TDMA MAC protocols. It is assumed that TDMA protocol divide time into frames with fixed duration. Generally, the TDMA protocol divided the slots into control slots and data slots. The data slots used to transmit data service are assigned through the exchange of control messages in the control slots. Before the data transmission, the protocol establishes a common slot schedule. The schedule may remain until traffic demands in the network changed.

In the TDMA network discussed, all the nodes that worked in half-duplex mode have the same ability of communication. If there are two nodes in the communication range of each other, they can establish symmetrical links in MAC layer. Then the whole networks can be represented with a connectivity graph G (N, E, ft), where, $N = \{n_1, n_2, \ldots, n_m\}$ is the set of nodes, $E = \{e_1, e_2, \ldots, e_k\}$ are the links between neighbor nodes and the $ft(e_k) = (n_i, n_j)$ represents a transmission from n_i to n_j used to denote the direction of the transmission. To

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simplify the analysis, we assume the bandwidths over wireless channel are the same which means all the nodes transmit data with the same data rate B. The Signal-to-noise Ratio (SNR) is associated with the distance between the two nodes.

DETAIL OF THE PROTOCOL

The MRSA protocol has two main functions which are the distributed on-demand slot reservation mechanism and the multi-hop scheduling scheme. The distributed on-demand slot reservation mechanism can make conflict-free slot reservation among all the nodes in two hops rang in a fully distributed manner according to the service demand. The multi-hop scheduling scheme can established an efficient slot schedule which can reduce the end-to-end delay along the route for a multi-hop service.

Frame structure: In the MRSA, there is only one kind of frame called Trans Frame and the frame structure is shown in Fig. 1.

The Trans Frame contains a contention phase followed by an Information Phase (Info phase). In the information phase, there are K Information Slots (IS) which is used for node to transmit data packets. In the contention phase, there are M Contention Slots (CS) which is used for node to carry out the process of contention to reserve an IS. The detail process of the contention contain five steps which is similar with FPRP but adopt new reservation mechanism, improved the efficiency of the slot assignment.

Distributed on-demand slot reservation mechanism: Before the reservation, node will evaluate the current traffic load and the slot resource had occupied. In this study, the number of packets had buffered in the output queue and the packets will be delayed for a multi-hop service but have not arrived had been regarded as the traffic load. When the node had got enough slot resources to support current traffic load, it should not contend for any more IS making other nodes with the service demand to use the valuable IS. Otherwise the node should contend for more slot resource on-demand.

If a node decide to contend a new IS, it should firstly choose the IS it wanted to forward the data packets and choose the CS randomly to carry out the process of contention. The MRSA protocol makes the M contention slots into n contention groups, contain m contention slots in every. The node should choose the index of CS, c_i, in current contention group which means that $0 \le c_i \le m-1$. When the time comes to c_i the node chose c_i will carry out

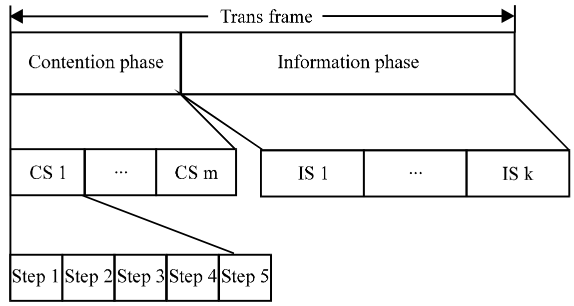

Fig. 1: Frame structure of MRSA

the process of five steps for contention. In the five steps reservation which is similar as FPRP, but MRSA also specify the index of IS it wanted and add cross layer information to support the multi-hop relay reservation. If there is only one node contend in c_i, the node will succeed in reserving the IS it wanted. By adopting this new reservation mechanism, MRSA can make conflict-free slot assignment in two hops contention field in distributed manner with high efficiency.

Multi-hop scheduling scheme: A multi-hop service in the network needs the cooperation of all nodes along the route. The traditional TDMA protocol could not obtain the routing information which belongs to the network layer. So, it only focuses on the link from one node to next hop node. In distributed Ad Hoc network, the node will know nothing about the multi-hop service until received the multi-hop service data packets. Then it will reserve the slot resource in the next frame for the multi-hop service. So, it will introduce large scheduling delay.

To reduce the scheduling delay, the MRSA protocol will ask for the routing information form network layer by cross layer mechanism. According to the routing information, the node will reserve the IS for current hop and inform the next hop node at same time. When the next hop node acknowledged the IS last hop node reserved, the MRSA protocol will help the next hop node to choose a proper IS close to last hop's IS in the same Trans Fame and finish the process of reservation according to the routing information from local network layer.

When a node initiates a multi-hop service, it will firstly obtain the routing information from network layer includes the destination address, the next hop address and the number of hops along the route. Then the source node will choose the IS s_0 for the first hop which should be close to the beginning of the Information Phase to left the reservation space for the nodes subsequent. So, the source node will calculate the contention range Rc which restricts the range s_0 within according to the number of hops H and the number of IS Kin the Trans Frame:

$$Rc = \left\lfloor \frac{K}{H} \right\rfloor \quad (1)$$

And the s_0 should be chosen randomly in the range:

$$s_0 \in [0, Rc] \quad (2)$$

After the chosen of the s_0, the source node will choose a CR to carry out the process of reservation mentioned before. At the same time the source node will inform the second hop node by adding the cross layer message to the reservation handshake packets. The structure of cross layer message is shown below:

```
Struct CrossLayer
{       Destination Address
Nexthop Address
Number Hops
Contention Range Rc
}
```

Once the source node have succeed in the reservation, the second hop node will confirm the IS s_0 source node reserved and obtain the cross layer message from source node. Then the second hop node will choose the IS s_1 randomly for the second hop which is:

$$s_1 \in [(s_0 + 1), (s_0 + 1 + Rc)] \quad (3)$$

Then the second hop node will choose a CR to carry out the process of reservation for s_1 and pass the cross layer message to next hop node. All the nodes on the route will make schedule one after another for the multi-hop service in this manner during the Contention Phase which is like relay race.

After that, the network will have established a virtual pipeline connected the source and destination node before relaying the multi-hop service data packets. It will reduced end-to-end delay obviously compare with the traditional protocol. What's more that the MRSA protocol will support the different priority of multi-hop service in probability by adjust Rc according to the demand of user. In the research, the OLSR is chosen as the network layer protocol which can offer the necessary cross layer information.

ANALYSIS AND SIMULATION

When data packets belong to multi-hop service were relayed from node n_i to n_{i+1} which are neighbours on the path, the time delay $D_{i\to i+1} = t_{i+1}$-t_i was introduced in where t_i and t_{i+1} are the time n_i and n_{i+1} relay the data packets, respectively to next hop. As in TDMA protocol, time has been divided into frames and slots. So, t_i and t_{i+1} can be normalized as follow:

$$\begin{cases} t_i = p_i T_{frame} + s_i T_{slot} \\ t_{i+1} = p_{i+1} T_{frame} + s_{i+1} T_{slot} \end{cases} (p_{i+1} \geq p_i) \quad (4)$$

where, p_i and p_{i+1} are the index of slots within the frame:

$$\begin{aligned} D_{i\to i+1} &= t_{i+1} - t_i \\ &= (p_{i+1} - p_i) T_{frame} \\ &\quad + (s_{i+1} - s_i) T_{slot} \end{aligned} \quad (5)$$

The mathematical expectation of $D_{i\to i+1}$ is:

$$E[D_{i\to i+1}] = E[p_{i+1} - p_i] T_{frame} + E[s_{i+1} - s_i] T_{slot} \quad (6)$$

According to MRSA protocol, after n_i reserved slot s_i the node n_{i+1} will seek for the slot s_{i+1} randomly within the prescriptive ruled range $[s_i + 1, s_i + 1 + Rc]$ in the same Trans Frame. So, p_{i+1}-p_i = 0 and the random variable (s_{i+1}-s_i) will follow the uniform distribution in [1, Rc + 1] which the mathematical expectation value is (Rc + 2)/2:

$$\begin{aligned} \therefore E[D_{i\to i+1}] &= E[s_{i+1} - s_i] T_{slot} \\ &= \frac{Rc + 2}{2} T_{slot} \end{aligned} \quad (7)$$

For a service with H hops path P, the end-to-end delay D_P is the sum of delay introduced by every hop:

$$\begin{aligned} D_P &= \sum_{i=0}^{H-1} D_{i\to i+1} \\ \Rightarrow E[D_P] &= \sum_{i=0}^{H-1} E[D_{i\to i+1}] \\ &= \frac{Rc + 2}{2} H T_{slot} \end{aligned} \quad (8)$$

It can be seen that, the expectation end-to-end delay E $[D_p]$ is proportional to R_c, H and T_{slot}.

In this study, the MRSA protocol was accomplished in the Qualnet simulator. The performance of MRSA protocol was evaluated on end-to-end delay under different traffic model comparing with FPRP protocol. The main reference of the scenario is in the Table 1.

The end-to-end delay of MRSA protocol with different Rc under different hops service is shown in Fig. 2.

As analyzed before, the end-to-end delay of the MRSA protocol has the linear relationship with the R_c and the hops of service. When the R_c get bigger the end-to-end delay increased more quickly. That's because

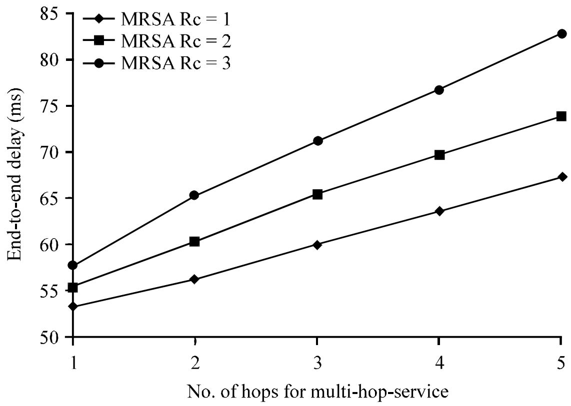

Fig. 2: End-to-end delay versus hops with different Rc

Table 1: Main reference of the scenario

Simulator	Qualnet V 5.0
Boundary	120×120 km
Service model	CBR
Number of nodes	25
Traffici load	10~60 Packet/s
Packet length	406 Byte
Transmission range	24 km
Simulation time	500s
Topology	random
MAC protocol	MRSA FPRP
Network protocol	OLSR
Band width on link	2 Mbps
Duration of CS	0.092 ms
Number of CS	100
Duration of IS	2 ms
Number of IS	25
Duration of trans frame	96 ms

the node will choose IS for next hop in a larger scope according to the Rc which will only add the length of few slots on end-to-end delay.

Figure 3 and 4 have showed the compared results on the performance of MRSA and FPRP in different service model. The FPRP (long) in Fig. 3 means that the FPRP has the same length with the MRSA in Trans Frame and the FPRP (short) means that the length of Trans Frame in FPRP is half of the MRSA. It can be seen from Fig. 3 that the end-to-end delay of both two protocols are the same when the service is just one hop away. But as the number of hops increasing, the delay of FPRP goes up more quickly. It is because that the node running the traditional TDMA protocol always knows nothing about the multi-hop service until it received the data packets. So, it usually reserve the IS in next Trans Frame after it received the data packets from last hop. This make the end-to-end delay of the traditional TDMA protocol proportional to the duration of the whole Trans Frame which is very large. Different from traditional TDMA protocol, the MRSA protocol can perceive the multi-hop service according to the cross layer information exchanged during the Contention Phase and reserve proper IS before the

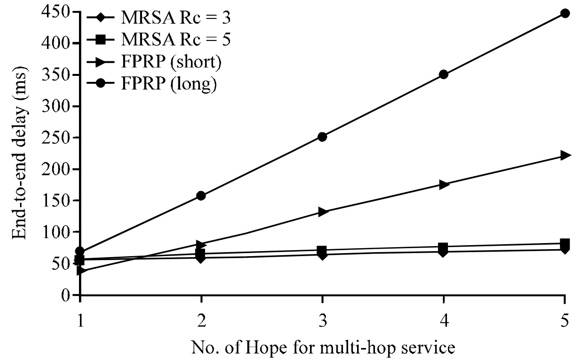

Fig. 3: End-to-end delay versus hops with different protocol

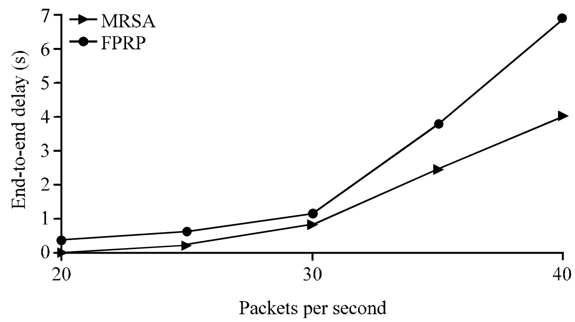

Fig. 4: End-to-end delay versus Traffic load

arriving of data packets. The performance of MRSA on end-to-end delay keep steady under different multi-hop service and keep less than 85 ms in this simulation.

Figure 4 illustrate the situation under different traffic load.

As, the traffic load increases both the delay of two protocols' end-to-end rises. When the traffic load is under 25 packets per second which can be supported by the networks, the end-to-end delay increased slightly. Once the traffic load exceed threshold, beyond 30 packets per second, the network will be saturated and the end-to-end delay will increased sharply. When the traffic load is beyond 35 packets per second, the end-to-end delay will exceed 2 seconds which is too high to be accepted. But the performance of MRSA is superior to FPRP under any traffic load in general.

CONCLUSION

To improve the performance of TDMA based protocol on end-to-end delay for multi-hop service, a new protocol named MRSA is proposed. The MRSA can make every node along the route to reserve proper slot with a multi-hop relay reserve mechanism using the cross layer information in distributed manner resulting the low end-to-end delay. The simulation result show that the MRSA protocol improved performance on end-to-end delay obviously compare with the traditional TDMA based protocol.

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REFERENCES

Djukic, P. and S. Valaee, 2009. Delay aware link scheduling for multi-hop TDMA wireless networks. IEEE/ACM Trans. Networking, 17: 870-883.

Ergen, S.C. and P. Varaiya, 2005. TDMA scheduling algorithms for sensor networks. Technical Report, University of California, Berkley.

Gandham, S., M. Dawande and R. Prakash, 2005. Link scheduling in sensor networks: Distributed edge coloring revisited. Proc. IEEE Annu. Joint Conf. Comput. Commun. Soc., 4: 2492-2501.

Hongyan, L. and S. Valaee, 2004. An efficient algorithm for time slot assignment in Ad Hoc networks. Proceedings of the 22nd Biennial Symposium on Communications, May 31-June 3, Kingston, Ontario, Canada, pp: 225-227.

Kodialam, M. and T. Nandagopal, 2003. Characterizing achievable rates in multi-hop wireless networks: The joint routing and scheduling problem. Proceedings of the 9th Annual International Conference on Mobile Computing and Networking, Sept. 14-19, San Diego, CA., USA, pp: 42-54.

Moscibroda, T. and R. Wattenhofer, 2005. Coloring unstructured radio networks. Proceedings of the 17th Annual ACM Symposium on Parallelism in Algorithms and Architectures, July 17-20, ACM., New York, pp: 39-48.

Parthasarathy, S. and R. Gandhi, 2004. Distributed algorithms for coloring and domination in wireless Ad Hoc networks. Found. Software Technol. Theor. Comput. Sci., 3328: 447-459.

Ramanathan, S. and E.L. Lloyd, 1993. Scheduling algorithms for multihop radio networks. IEEE/ACM Trans. Network., 1: 166-177.

Wang, H., X. Zhang, F. Nait-Abdesselam and A. Khokhar, 2010. Cross-layer optimized MAC to support multihop QoS routing for wireless sensor networks. IEEE Trans. Vehic. Technol., 59: 2556-2563.

Xu, M., M. Zhao, Z. Song and S. Li, 2006. An on-demand and dynamic slot assignment protocol for Ad Hoc networks. Proceedings of the Asia-Pacific Conference on Communications, Aug. 31-Sept. 1, Busan, pp: 1-5.