Wireless Token Ring Protocol

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Abstract— **The Wireless Token Ring Protocol (WTRP) is a medium access control protocol for wireless networks in Unmanned Aerial Vehicles. It supports quality of service in terms of bounded latency and reserved bandwidth. This quality of service guarantee is critical in mesh stability of the formation of the vehicles. The communication of the speed and the velocity of the lead vehicle to all other vehicles in the formation had been shown to be sufficient for mesh stability of the system.**

WTRP is efficient in the sense that it reduces the number of retransmissions due to collisions. It is fair in the sense that each station takes a turn to transmit and is forced to give up the right to transmit after transmitting for a specified amount of time. It is a distributed protocol that supports many topologies since not all stations need to be connected to each other or to a central station. It can be used with an admission control agent for bandwidth or latency reservations. WTRP is robust against single node failure. WTRP is designed to recover gracefully from multiple simultaneous faults.

Keywords—

Medium Access Control, Wireless Token Ring Protocol, IEEE802.11, IEEE802.4, Quality of Service, Intelligent Transportation Systems, Automated Highway Project, Mission Critical Systems.

I. INTRODUCTION

In an unreliable medium such as wireless, problem of providing quality of service (QOS) at the network layer using queuing and routing techniques is not sufficient. QOS must also be addressed at the data-link layer. The IEEE 802.11[1] in PCF (Point Coordination Function) mode, the HiperLAN[2], and Bluetooth[3] achieve bounded latency by having a central station poll the slave stations. Most academic research has focused on this centralized approach [4] [5]. The centralized approach is suitable for networks where only the last hop is wireless. In the centralized approach, the network is managed centrally from

a central station. This is a limitation in wireless networks with ad-hoc topologies.

The Wireless Token Ring Protocol (WTRP) discussed in this paper is a distributed medium access control protocol for ad-hoc networks. The advantages of a distributed medium access control protocol are its robustness against single node failure, and its support for flexible topologies, in which nodes can be partially connected and not all nodes need to have a connection with a master.

WTRP is to be deployed initially in the University of California at Berkeley PATH Advanced Vehicle Safety Systems Program[6], the CALTRANS-PATH Demonstration 2002, and the Berkeley Aerobot project[8]. These projects impose stringent bandwidth, latency, and speed of failure recovery requirements on the medium access protocol. The platoon mode of the automated highway project involves up to 20 nodes in each platoon, and requires that information (approximately 100 bytes per vehicle for speed, acceleration, and coordination maneuvers) be transmitted every 20ms. The failure recovery time for the communication system must be within 40ms.

As in the IEEE 802.4[9] standards, WTRP is designed to recover from multiple simultaneous failures. One of the biggest challenges that the WTRP overcomes is partial connectivity. To overcome the problem of partial connectivity, management, special tokens, additional fields in the tokens, and new timers are added to the protocol. When a node joins a ring, it is required that the joining node be connected to the prospective predecessor and the successor. The joining node obtains this information by looking up its connectivity table. When a node leaves a ring, the predecessor of the leaving node finds the next available node to close the ring by looking up its connectivity table. Partial connectivity also affects the multiple token resolution protocol (deleting all multiple tokens but one). In a partially connected network, simply dropping the token whenever a station hears another transmission is not sufficient. To delete tokens that a station is unable to hear,
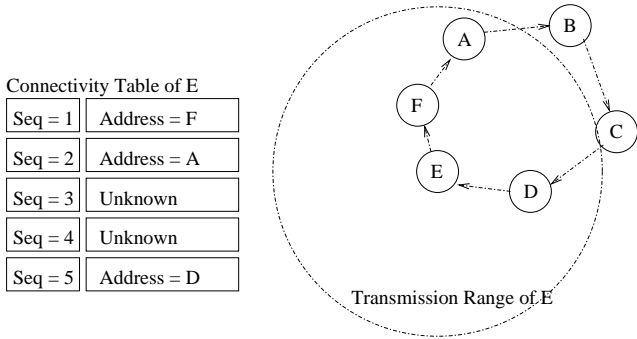
Fig. 1. Connectivity Table

Fig. 2. Joining

we have designed a unique priority assignment scheme for tokens. Stations only accept a token that has greater prioirity than the token the station last accepted. The WTRP also has algorithms for keeping each ring address unique, to enable the operation of multiple rings in proximity.

II. PROTOCOL OVERVIEW

In the WTRP, the successor and the predecessor fields of each node in the ring define the ring and the transmission order. A station receives the token from its predecessor, transmits data, and passes the token to its successor. Here is an illustration of the token frame.

FC	RA	DA	SA	Seq	GenSeq	
1	6	6	6	4	4	bytes

FC stands for Frame Control and it identifies the type of packet, such as Token, Solicit Successor, Set Predecessor, etc. In addition, the source address (SA), destination addresses (DA), ring address(RA), sequence number(Seq) and generation sequence(GenSeq) number are included in the token frame. The ring address refers to the ring to which the token belongs. The sequence number is initialized to zero and incremented by every station that passes the token. The generation sequence number is initialized to zero and incremented at every rotation of the token by the creator of the token.

The Connectivity manager resident on each node tracks transmissions from its own ring and those from other nearby rings. By monitoring the sequence number of the transmitted tokens, the Connectivity Manager builds an ordered list of stations in its own ring. The Connectivity Table of the manager holds information about its ring (Figure 1). In Figure 1, station E monitors the successive token transmission from F to D before the token comes back to E. At time 0, E transmits the token with sequence number 0, at time 1, F transmits the token with the sequence number 1, and so on. E will not hear the transmission from B and C, but when it hears transmission from D, E will notice
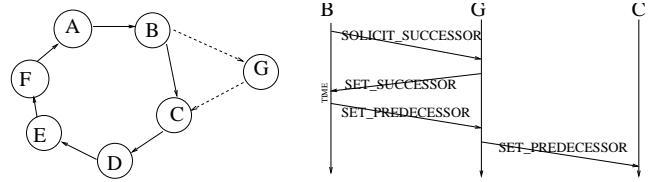
that the sequence number has been increased by 3 instead of 1. This indicates to E that there were two stations that it could not hear between A and D.

The Ring Owner is the station that has the same MAC address as the ring address. A station can claim to be the ring owner by changing the ring address of the token that is being passed around.

Stations rely on implicit acknowledgements to monitor the success of their token transmissions. An implicit acknowledgement is any packet heard after token transmission that has the same ring address as the station.

Each station resets its IDLE_TIMER whenever it receives an implicit acknowledgement. If the token is lost in the ring, then no implicit acknowledgement will be heard in the ring, and the IDLE_TIMER will expire. When the IDLE_TIMER expires, the station generates a new token, thereby becoming the owner of the ring.

To resolve multiple tokens (to delete all tokens but one), the concept of priority is used. The generation sequence number and the ring address define the priority of a token. A token with a higher generation sequence number has higher priority. When the generation sequence numbers of tokens are the same, ring addresses of each token are used to break the tie. The priority of a station is the priority of the token that the station accepted or generated. When a station receives a token with a lower priority than itself, it deletes the token and notifies its predecessor without accepting the token. With this scheme, it can be shown that the protocol deletes all multiple tokens in a single token rotation provided no more tokens are being generated[10].

The ring recovery mechanism is invoked when the monitoring node decides that its successor is unreachable. In this case, the station tries to recover from the failure by reforming the ring. The strategy taken by the WTRP is to try to reform the ring by excluding as small a number of nodes as possible. Using the Connectivity Manager, the monitoring station is able to quickly find the next connected node in the transmission order. The monitoring station then sends the SET_PREDECESSOR token to the next connected node to close the ring.

WTRP allows nodes to join a ring dynamically, one at a time, if the token rotation time (sum of token hold-
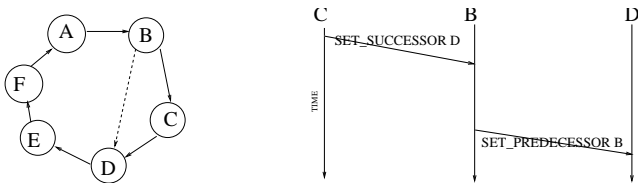
Fig. 3. Exiting

Fig. 4. Implementations

ing times per node, plus overhead such as token transmission times) would not grow unacceptably with the addition of the new node. As illustrated in Figure 2, suppose station G wants to join the ring. Let us also say that the admission control manager on station B invites another node to join the ring by sending out a SOLICIT_SUCCESSOR. The Admission Control Manager waits for the duration of the response window for interested nodes to respond. The response window represents the window of opportunity for a new node to join the ring. The response window is divided into slots of the duration of the SET_SUCCESSOR transmission time. When a node that wants to join the ring, such as G, hears a SOLICIT_SUCCESSOR token, it picks a random slot and transmits a SET_SUCCESSOR token. When the response window passes, the host node, B can decide among the slot winners. Suppose that G wins the contention, then the host node passes the SET_PREDECESSOR token to G, and G sends the SET_PREDECESSOR to node C, the successor of the host node B. The joining process concludes.

As shown in Figure 3, suppose station C wants to leave the ring. First, C waits for the right to transmit. Upon receipt of the right to transmit, C sends the SET_SUCCESSOR packet to its predecessor B with the MAC address of its successor, D. If B can hear D, B tries to connect with D by sending a SET_PREDECESSOR token. If B cannot hear D, B will find the next connected node, in the transmission order, and send it the SET_PREDECESSOR token.

The ring address of a ring is the address of any one of the stations in the ring. The station is called the owner of the ring. In the example, the owner of ring A is station A. Because we assume that the MAC address of each station is unique the ring address is also unique. The uniqueness of the address is important, since it allows the stations to distinguish between messages coming from different rings.

To ensure that the ring owner is present in the ring, when the ring owner leaves the ring, the successor of the owner claims the ring address and becomes the ring owner. The protocol deals with the case where the ring owner leaves the ring without notifying the rest of the stations in the ring as follows. The ring owner updates the generation
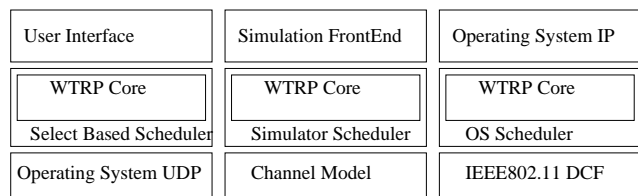
sequence number of the token every time it receives a valid token. If a station receives a token without its generation sequence number updated, it assumes that the ring owner is unreachable and it elects itself to be the ring owner.

III. IMPLEMENTATIONS

We implemented the WTRP on top of 2 Mbps WaveLAN[11] PCMCIA card that implements the IEEE802.11[1] protocol. WTRP uses DCF (Distributed Coordinated Function) mode of IEEE802.11. This is done by prepending the token ring header to the IP packet and broadcasting all packets in peer-to-peer mode.

We have three different implementations of WTRP as shown in Figure 4. All three implementations use the same protocol core. This sharing of codes is made possible by the implementation of Linux kernel libraries for packet manipulations and event scheduling in user space.

The importance of the UDP implementation (Figure 4) is that it is platform independent. In a managed network, applications can reduce the frequency of packet collisions by sending the UDP packet using the UDP interface. In this case, WTRP is used as a transmission scheduling method rather than a medium access control. We have shown the efficiency of the implementation by streaming without jitter 1 Mbps video without buffering on the WaveLAN cards.

The simulator (Figure 4) allows testing and simulation of the same WTRP core shared by all implementations. This design of simulator is advantageous since it nullifies the need to develop separately for simulation and for deployment. The separated development is not only expensive in terms of added developmental costs, but also increases the chance of failure to identify potential problems of the protocol since the protocol that is tested in simulations and deployed is often different.

In terms of mobility model eof the simulator, a node can be assigned one of implemented random movement patterns or follow a prefined path. The mobility is visualized in the Network Animator[12] by generating a log that Network Animator understands. A screen shot of the visualization is shown in Figure 5. In terms of the channel model, the simulation models a simple Direct Se-
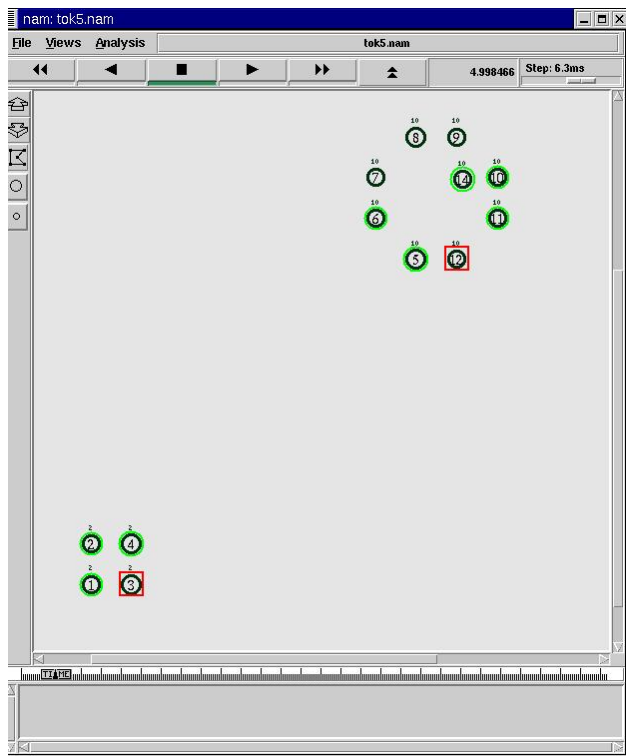
Fig. 5. Visualization of the Simulator

quence Sequence Spectrum (DSSS) capturing effect based on transmission to interference ratio, free space wave propagation, and underlying CSMA radio. Multipath or fading affect is not modeled.

The Linux kernel module is developed for kernel version 2.2.19, and it is inserted between the IP and Wave-LAN libraries. The next section (Section IV) shows the performance analysis conducted on the Linux kernel module.

IV. PERFORMANCE

In the trial shown in Figure 6, a large file size 5830080 Bytes was transferred using FTP between two nodes running the token ring medium access protocol. Figure 7 shows the trial done with three nodes. A file of size 7403520 bytes was transferred. The LINUX clock resolution was set at 2048Hz. The token rotation time was measured at the FTP server for each token rotation. The file transfer of the same file was done three times with a single transfer, 2 concurrent transfers, and 3 concurrent transfers. The three peaks in Figure 6 and Figure 7 correspond to the three FTP transmission periods.

From the figure, one can see that the token rotation time did not increase in spite of an increased number of simultaneous transmissions. Rather, the transfer took longer to complete in direct proportion to the number of concurrent
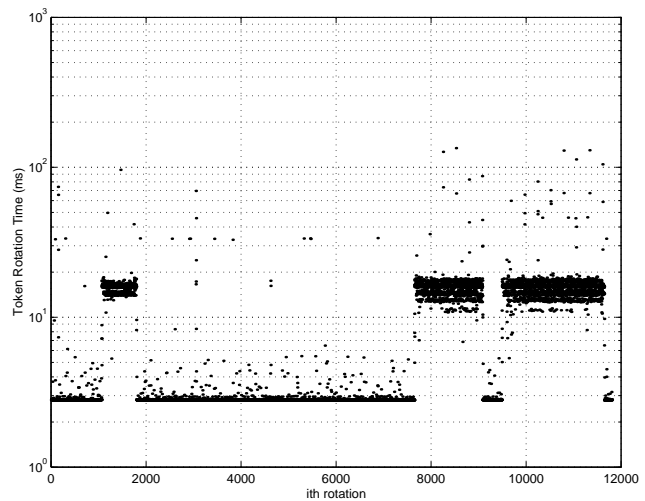

Fig. 6. Token Rotation Time during FTP (Two Nodes, 2048Hz)
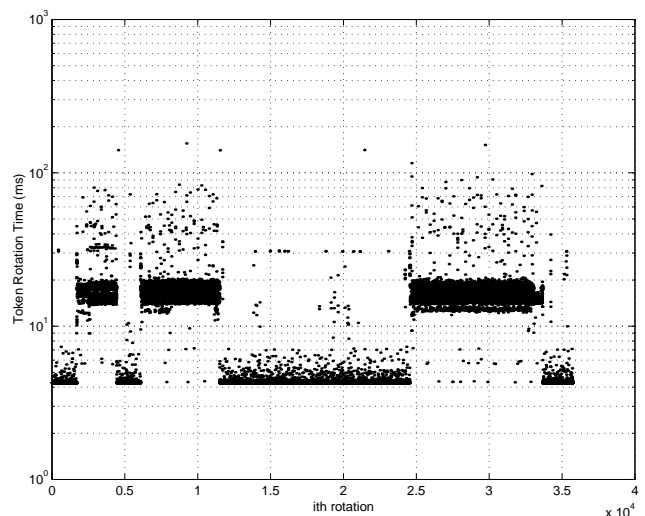

Fig. 7. Token Rotation Time during FTP (Three Nodes, 2048Hz)

FTP transfers. This bound on latency is the most salient property of the token ring protocol. It enables real time application support.

The test results seem to indicate that WTRP is scalable with the number of nodes. The following trials are done to see this. The scalability of the system response can be measured by observing the increase in token rotation time as the number of the nodes in the ring is increased. As expected, the mean token rotation time increases linearly with the number of nodes in the ring as shown in Figure 8. The standard deviation of token rotation time is also indicated in Figure 8. At least with small number of nodes, the standard deviation increased linearly. In addition, token rotation time is well contained. Less than 0.01% of the time the rotation time took longer than 40ms during the trial (0.0017% for Figure 7 and 0.0064856% for Figure 6).
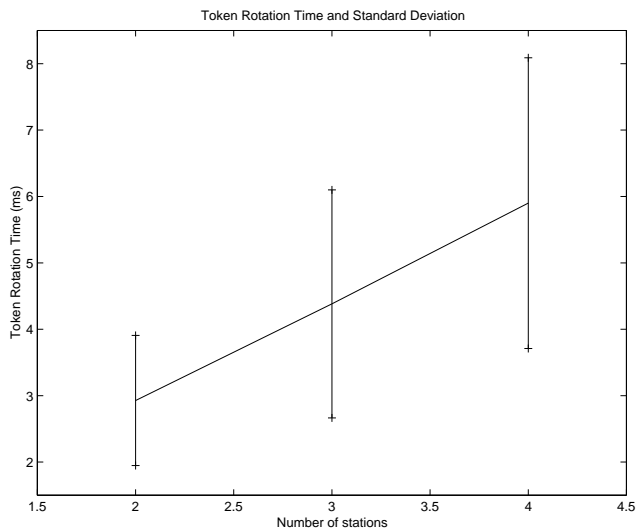
Fig. 8. Standard Deviation of the Token Rotation Time

Fig. 9. Instantaneous Throughput

V. COMPARISON WITH THE IEEE802.11 IN DCF MODE

The token ring protocol in its current implementation is disadvantaged relative to the original IEEE802.11 driver because the token ring protocol is implemented on top of IEEE802.11 in DCF mode, incurring all the overhead that is associated with IEEE802.11 plus the overhead from the token ring. The overhead is the increased computation time and packet header size. In spite of these disadvantages, we find that WTRP distributes bandwidth fairly among the stations compared to IEEE802.11 as shown in Figure 9. The fairness issue is the property of WTRP since every station has equal chance to get the bandwidth. IEEE802.11, on the other hand, suffers from fairness since some stations are at a disadvantage in access to the shared channel and can suffer severe throughput degradation when load to channel is high. Under heavy load, the token ring implementation performs better than the IEEE802.11 in DCF mode. This is shown in Figure 10. In the figure, the aggregate FTP bandwidth is plotted against the number of simultaneous FTP transfers. Both cases involved number of nodes equal to the number of simultaneous FTP transfers. The FTP was done as follows. For the case of two simultaneous transfers, one transfers went from station 1 to station 2 another from station 2 to station 1. For the case of three simultaneous transfers, 1 to 2, 2 to 3, and 3 to 1.

In Figure 10, the circle represents the IEEE802.11 in DCF mode and the triangular represents the token ring protocol. We observed a increase and a decrease in IEEE802.11. The decrease in the throughput is expected since the number of collisions increase in a CSMA
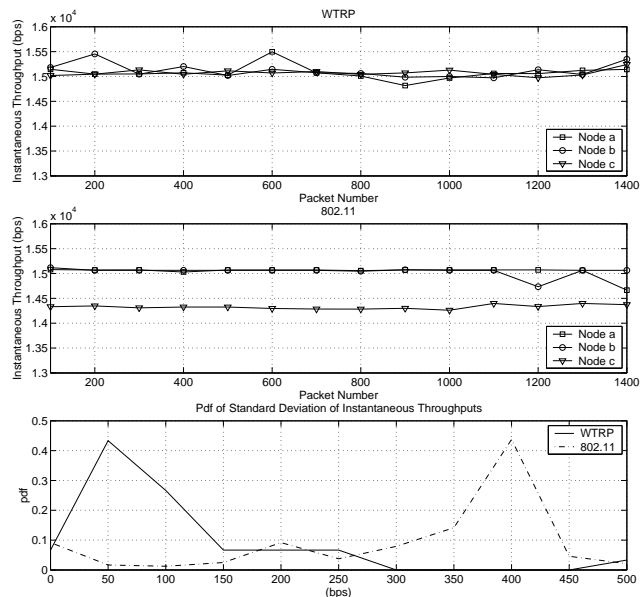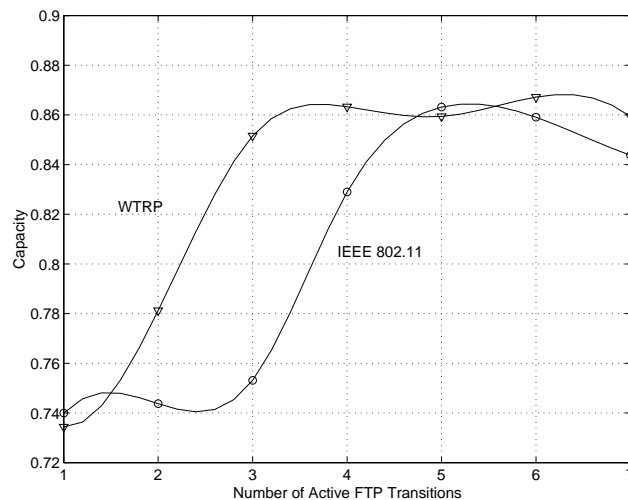

Fig. 10. FTP performance (IEEE802.11 in DCF mode vs. Token ring)

medium access control and after the saturation point, performance of IEEE802.11 degrades [7].

The performance intuitively should be constant in Wireless Token Ring case but improves in the simulation when going from 1 to 3 simultaneous transfers. This can be explained as follows. Since for all trials in Figure 10, the *Maximum Token Rotation Time* varies. When there are few nodes in the network, the nodes can not operate at saturation point. As a result, the nodes can not use all of the capacity.

The need for retransmission of the data due to collisions is eliminated since there is no collision in the token ring implementation. We found that the token ring actually per-

forms better when there are more than three simultaneous transfers.

The Centralized approach (802.11 PCF mode) uses the star topology, meaning that all slave nodes need to have a connection with the master. It is then easier to manage the network since all management information can be stored at the master. However, the approach is vulnerable to a single node failure at the master.

VI. CONCLUSION

Even though the token ring protocol was implemented on top of the IEEE802.11 in DCF mode, we found that the token ring performs well or even better under heavy load. We have designed a protocol that is fast in terms of recovery (since there were several tokens lost during the tests) and efficient in terms of header size. One reason for the fast recovery is the use of a connectivity cache in each station. The performance results also show that we have a software implementation that is useful under a controlled application environment when utilized on top of an arbitrary network interface card.

The consistency of the token rotation time, regardless of the number of simultaneous transmissions is key to bounding the medium access latency. This perhaps is the most valuable feature of the wireless token ring protocol, since this is necessary in real time applications. In fact, the development of IEEE802.4 was initiated by people from General Motors and other companies interested in factory automation[13]. It has been established as a "mandatory protocol within the General Motor's manufacturing automation protocol (MAP)"[14]. Features such as bounded latency and robustness against multiple node failures are some of the reasons for this choice. Our design bring the same bounded latency and robustness features to the wireless medium. Moreover, WTRP accomodates ad-hoc topologies.

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