Wireless Token Ring Protocol-Performance Comparison with IEEE 802.11*

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Abstract

The paper presents the performance advantage of Wireless Token Ring Protocol (WTRP) versus IEEE 802.11 in DCF mode. WTRP is a medium access control (MAC) protocol and is designed to provide quality of service in WLANs. WTRP supports guaranteed QoS in terms of bounded latency and reserved bandwidth which are crucial constraints of the real time applications and unapplicable in a IEEE 802.11 network. WTRP is a distributed MAC protocol and partial connection is enough for full connectivity. The stations take turn to transmit and are forced to suspend the transmission after having the medium for a specified amount of time. WTRP is robust against wireless medium imperfections. The DCF mode of IEEE 802.11, also a distributed MAC protocol, is based on contention among stations and is not homogeneous due to the existence of hidden terminals and random behavior. Consequently, QoS is not provided.

1 Introduction

Wireless local area networking is introduced to provide wireless connectivity to stations that require rapid deployment. In wireless networks, participating stations can join or leave the network at any moment in time. IEEE 802.11 protocol is introduced in 1997 with a medium access control (MAC) protocol and several physical layer signalling techniques [11]. IEEE 802.11 MAC provides to two different access mechanisms based on contention (Distributed Coordination Function (DCF)) and polling (Point Coordination Function (PCF)). Due to the existence of hidden terminals and partially connected network topology, contention among stations in a wireless network is not homogeneous. Some stations can suffer severe throughput degradation in access to the shared channel when load of the channel is high [7], which also results in unbounded medium access time for the stations and unfair resource distribution per station [8], [9], [12]. This challenge is addressed as quality of service (QoS) in communication networks.

WTRP-Wireless Token Ring Protocol is a MAC protocol intended to provide QoS in terms of bounded delay and reserved bandwidth. WTRP is built based on a distributed approach. Its advantages are robustness against single node failure, and its support for flexible topologies, in which nodes can be partially connected for full connectivity and not all nodes need to have a connection with a central controller. Current wireless distributed MAC protocols such as the IEEE 802.11 (DCF mode) [11] and the ETSI HIPERLAN [10] do not provide QoS guarantees that are required by some applications. In particular, medium is not shared fairly among stations and medium-access time can not be controlled.

WTRP is an ongoing work of [1] and previously presented in [3], [4], [5]. The latest version [2] includes improvements in the packet frames in order to convey more information to perform robust and quick network creation. A new finite state machine is introduced that response faster to the wireless medium changes than [4]. WTRP was first deployed for the automated highway project of CALTRANS [6] and now is extended to home and local area networks [2].

The outline of the paper is as follows; We explain the MAC protocol of IEEE 802.11 in DCF mode and the MAC protocol of WTRP in Section 2 and 3 respectively. We present the performance results in Section 4 and conclude the paper in Section 5.

2 MAC Protocol of IEEE 802.11

IEEE 802.11 MAC protocol in DCF mode is based on Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme. The medium access mechanism has two important modules: carrier sense and backoff. Following the Figure 6, station waiting in the idle state senses the medium before making any attempt to transmit. There are two different carrier sense mechanisms: Virtual carrier sense (VCS) and physical carrier sense (PCS). VCS is determined by the network allocation vector (NAV) which is set according to time specified in the duration

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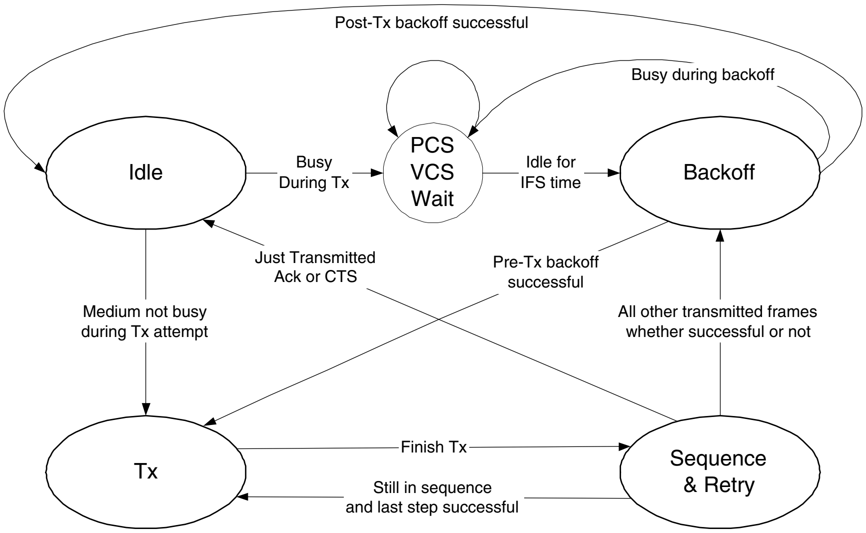

Figure 1. Main Flow for IEEE 802.11 DCF MAC Protocol

field of packets [11]. This gives station to understand the time, the channel is occupied, due to an ongoing transmission. On the other hand, PCS is a notification mechanism from physical layer to MAC layer saying that there is no signal detected. By combining VCS and PCS, MAC implements "collision avoidance" mechanism of CSMA/CA [11],[12]. The station before initiating any transmission first checks VCS and then senses the medium for a DIFS time by PCS.

If a station finds the medium busy, it waits until the carrier sense mechanism notifies the station that the medium is idle. Next, the station goes to "backoff" state from "PCS & VCS" state and selects a backoff interval uniformly out of a contention window [11]. Contention window doubles in every unsuccessful transmission, consequently the station waits longer in backoff. If the station senses a transmission while it counts down in "backoff" state, it suspends the transmission and goes back to carrier sense state and waits until the medium becomes idle and then starts counting down from where it stopped. After backoff, the station transmits the packet in "Tx" state. The station waits for ACK or CTS frame to make sure that the transmission is successful in "Sequence & Retry" state. In case of unsuccessful transmission, it doubles its contention window and increments its retry counter. When the retry count reaches maximum value, station gives up transmitting that packet. An illustration of timing diagram is shown in Figure 3.

A station reserves the medium by sending a Request-To-Sent (RTS) frame. The stations receiving the RTS frame stop transmitting except the station to whom the RTS is destined. Destined station sends CTS frame to acknowledge the transmitting station that it is ready to receive. RTS and CTS frames contains duration fields in which the other stations learn how long the medium will be busy and set their NAVs accordingly. As it can be seen from Figure 3, stations wait SIFS time between packets [12]. The RTS/CTS mechanism is disabled when the data size is below the RTS threshold, specified in the standard [11].

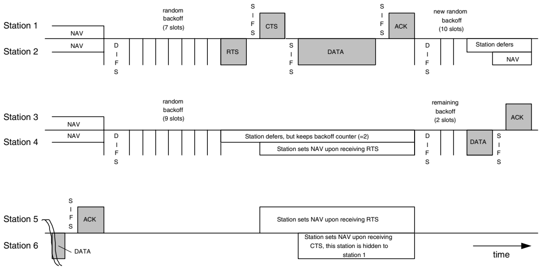

Figure 3. Timing Diagram for IEEE 802.11

3 MAC Protocol of WTRP

Main flow of WTRP as shown in Figure 6 is designed to compete with wireless medium facts. WTRP implements several modules to cope with "mobility", "interference and collision avoidance", and "guaranteed transmission". The WTRP constructs a ring wherein the transmission proceeds in one direction along the ring. Each station has a successor and a predecessor which is enough for the ring to be fully connected. An illustration of timing diagram is shown in Figure 5[1]. Each station is given a certain time called *token holding time* (THT). After receiving the *token* frame, station is allowed to transmit packet up to a THT and passes the *token* to its successor. Assume that there are *N* stations in a ring. We define T_n to be the time wherein station S_n transmits between it gets and it releases the *token*. Time that takes for one rotation of token is bounded by Maximum Token Rotation

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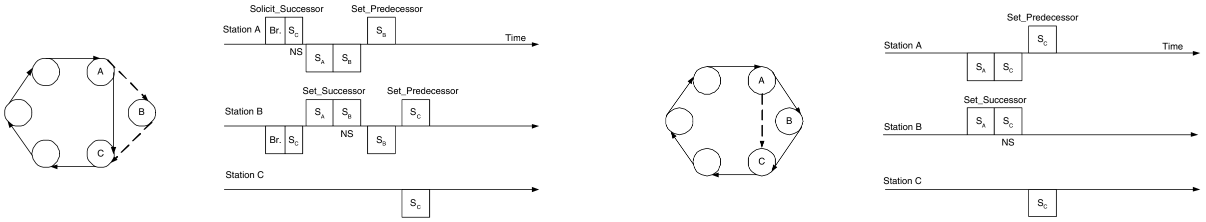
[1] *PROP* stands for propagation time of a signal in the medium.

FC	RA	DA	SA	NoN	GenSeq	Seq	
1	6	6	6	2	4	4	bytes

Figure 2. Token Frame



(a) Joining

(b) Exiting

Figure 4. Management Procedures

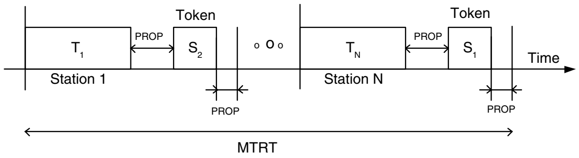


Figure 5. Timing diagram for WTRP

Time (MTRT) where the equality $N.THT <= MTRT$ holds. As a result, T_n can range from 0 to *token holding time* (THT). A station first sends its data during T and if there is enough time left, the station decides to send invitation to other nodes outside. a *token* frame contains information for ring management. An illustration of the *token* frame is seen in Figure 2[2]. If there is one station in the ring, it is called *self ring*. Each ring has a **Ring Owner** which is the station that has the same MAC address as the ring address. A station who first creates the self ring assigns himself as the ring owner at the beginning. A station can claim to be the ring owner by changing the ring address of the token that is being passed around. The uniqueness of the MAC address allows the stations to distinguish between messages coming from different rings. When the ring owner leaves the ring, the successor of the owner claims the ring address and becomes the ring owner. 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.

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 local list of stations in its own ring and an unordered global list of stations outside its ring.

Successful token transmission rely on implicit acknowledgements. An implicit acknowledgement is any packet heard after token transmission that has the same ring address as the station. Another acceptable implicit acknowledgement is any transmission from a successive node regardless of the ring address in the transmission. A successive node is a station that was in the ring during the last token rotation. If the station does not receive an implicit ACK for a MTRT after passing the *token*, the station generates a new token, thereby becoming the owner of the ring.

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 forming the ring again. Using the Connectivity Manager, the monitoring station is able to quickly find the next connected node in the transmission order.

Multiple token resolution (to delete all tokens but one in the ring) is based on the concept of priority. 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 proved that the protocol deletes all multiple tokens in a single token rotation pro-

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[2] *Frame Control* (FC) identifies the type of packet, such as $\{$*Token, Solicit Successor Token, Set Predecessor Token, Claim Token, Set Successor Token, Token Deleted Token, Data*$\}$. *Source address* (SA) is the station where the packet is originated. *Destination address* (DA) determines the station where the packet is destined. *Ring address* (RA) refers to the ring to which the token belongs. *Sequence number* (Seq) is initialized to zero and incremented by every station that passes the token. *Generation sequence number* (GenSeq) is initialized to zero and incremented at every rotation of the token by the creator of the token. *Number of nodes* (NoN) in the ring is represented in the token frame and calculated by taking the difference of sequence numbers in one rotation.

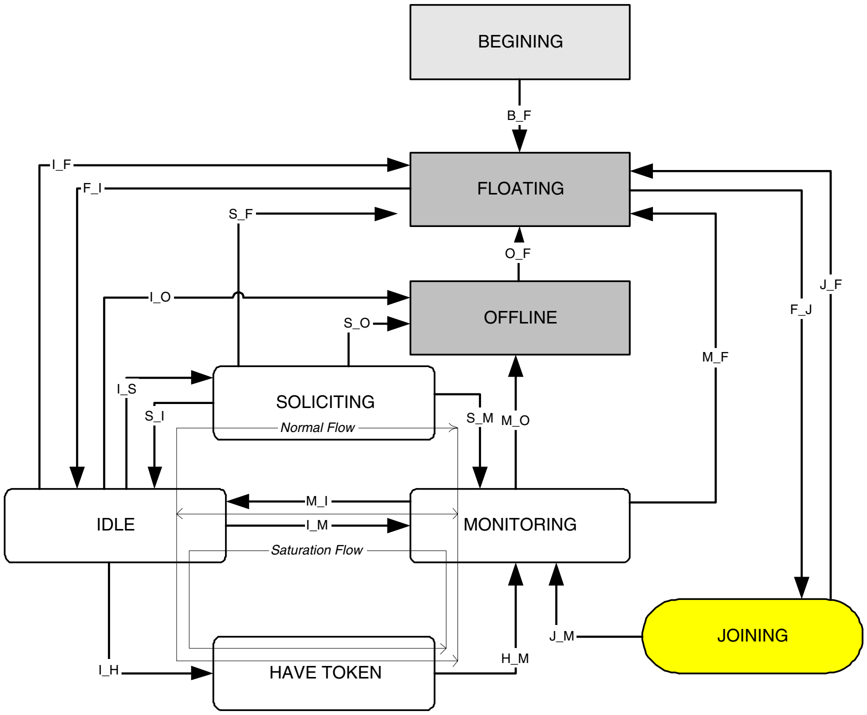

Figure 6. Main Flow for WTRP

vided no more tokens are being generated [2], [3]. "Interference avoidance" from stations outside of ring is done by introducing *floating* and *offline* states wherein a station suspends transmission and waits to join a ring. **Interference** is eliminated by including number of nodes (NoN) field into the token packet. If NoN is set to MAX_NoN, the station changes its channel and searches for another ring. Otherwise, the station either waits for an invitation, *solicit_successor* token, to become a ring member or changes its channel to search for another ring in *floating* state. As a result, a newcomer station never interferes with the ring. A station goes to *offline* state when it is somehow put out of the ring. Waiting time in *offline* state is more than MTRT resulting that ring is recovered before the station is ready to join.

"Collision avoidance" in the same ring is eliminated by the *idle* state wherein a station suspends transmission until it gets the *token*. "Equal bandwidth share" is controlled by *have token* state wherein the station transmits packets as long as THT. If there is enough room for a new station, station goes to "soliciting" state and sends invitation. *Monitoring* state is for "guaranteed transmission" wherein a station monitors for a implicit ACK and retransmits in case of a failure.

WTRP has *joining* and *soliciting* states where inviting and joining processes are handled. **Joining** to a ring is dynamic and handled one at a time until the token rotation time (sum of token holding times per node plus overhead such as token transmission times) reaches MTRT. 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 *B* (See Figure 4(a)) wants to join the ring, *B* goes to *joining* state after hearing a *solicit_successor* token. It picks a random slot and transmits a *set_successor* token. When the response window passes, the host node, *A* can decide among the slot winners. Suppose that *B* wins the contention, then the host node passes the *set_predecessor* token to *B*, and *B* sends the *set_predecessor* to node *C*, the successor of the host node *A* and *B* shifts to *monitoring* state otherwise if the joining is not successful, *B* goes back to *floating* state.

Leaving the ring can be with or without notification. Suppose station *B* (See Figure 4(b)) wants to leave the ring. First, *B* waits for the right to transmit in *idle* state. Upon receipt of the right to transmit, *B* sends the *set_successor* packet to its predecessor *A* with the MAC address of its successor, *C* in *have token* state. If *A* can hear *C*, *A* tries to connect with *C* by sending a *set_predecessor* token. If *A* cannot hear *C*, *A* will find the next connected node, in the transmission order, and sends it the *set_predecessor* token. If *B* fails, then station *A* understands the failure when it did not get the implicit acknowledgement and tries to close the ring.

The modules introduced above manage the stations in a proper manner and creates robust rings. If there is no stations that leaves the ring with or without notice, it is proven and shown that the number of stations in the ring monotonically increases [3], [2]. If the station leaves the ring for any reason it has been shown in [2]

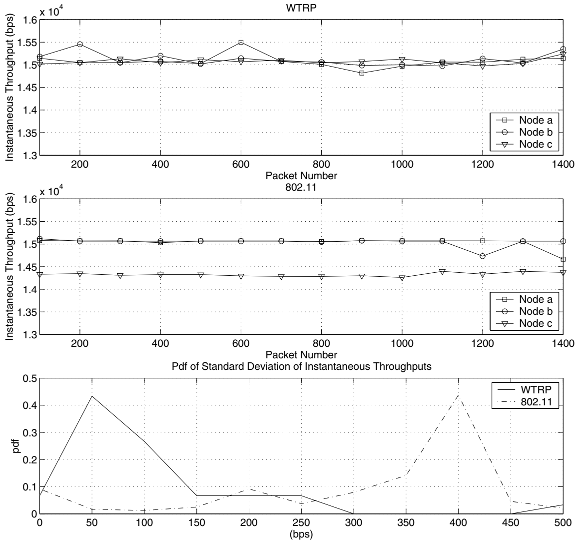

Figure 7. Instantaneous Throughput

that the ring does not collapse and ring recovers immediately.

We highlight some of the important distinctions of WTRP over IEEE 802.11.

- WTRP has deterministic MAC protocol but IEEE 802.11 DCF has randomized MAC protocol. This results in performance degradation at IEEE 802.11 side since there appears idle time that can be utilized.

- Partial connectivity is another property of WTRP. Unlike IEEE 802.11 network, for fully connected network, each station only need to connect with two stations that are one hop ahead and one hop behind the station. Consequently, the coverage area of the network increases.

- WTRP uses implicit ACK, explicit ACK of IEEE 802.11 is eliminated and overhead, it introduces, is diminished.

- WTRP puts the transmission in order. The stations belonging to the same ring does not cause any interference to the station that is transmitting. Stations outside of the ring suspend their transmission and wait for an invitation or change their channel. Joining process is handled by the ring without causing any interference. This reduces the collision probability significantly compared to IEEE 802.11.

- MTRT bounds the token rotation time therefore the next time the station gets right of transmit can be pre-fixed. This is an important property that decreases the delay.

- One THT is given to each station to transmit packets. It is strictly bounded by time. This fair bandwidth distribution is crucial for QoS networks and not guaranteed in IEEE 802.11 network.

4 Performance Analysis

IEEE 802.11 suffers from fairness since it is a contention based medium access scheme but WTRP provides fair distribution of resources. Figure 7 shows the instantaneous throughput of three nodes. We can see that one of the station is suspended in IEEE 802.11 and has less throughput than the others. On the other hand, there is a fair distribution in WTRP since WTRP offers equal bandwidth and equal transmission right to each station.

Third graph in Figure 7 shows the statistical distribution of the standard deviation of instantaneous throughputs after we perform the test many times. Increase in the deviation means increase in the unfairness and deviation of WTRP is closer to zero than that of IEEE 802.11.

In a wireless network without proper organization, each node causes an increase in collision probability. As a result, network size matters to protocols that suffer from collision such as IEEE 802.11. We increase the number of nodes in the network and each node sends 100bytes with 50ms packet generation rate. As it can be inferred from the Figure 8(a), WTRP performs better than IEEE 802.11 and the performance difference increases as the network grows in size. We expect higher difference when there is no overhead due to implementing the WTRP on top of IEEE 802.11 card. Same test is also performed with Poisson packet generation rate when the parameter is 50ms. Results show that throughput is higher in WTRP than IEEE 802.11 but difference of their performance varies. Since Poisson behavior does not affect WTRP but affects IEEE 802.11 unpredictably.

In Figure 8(b), the aggregate FTP bandwidth is plotted against the number of simultaneous FTP transfers. Both cases involved number of nodes are equal to the number of simultaneous FTP transfers. For instance, for the case of three simultaneous transfers, the transfers are from the station 1 to the station 2, from the station 2 to the station 3, and from the station 3 to the station 1.

In Figure 8(b), we observe a concave curve in IEEE 802.11. The decrease in the throughput is expected since the number of collisions increases in a CSMA medium access control as the network grows in size. After the saturation point, performance of IEEE 802.11 degrades [7]. The performance intuitively should be constant in WTRP but in the simulation, the throughput is less when the number of simultaneous transfers are between 1 and 3. This is because if there are few nodes in the network the nodes can not operate at saturation point. As a result, the nodes can not utilize all of the capacity.

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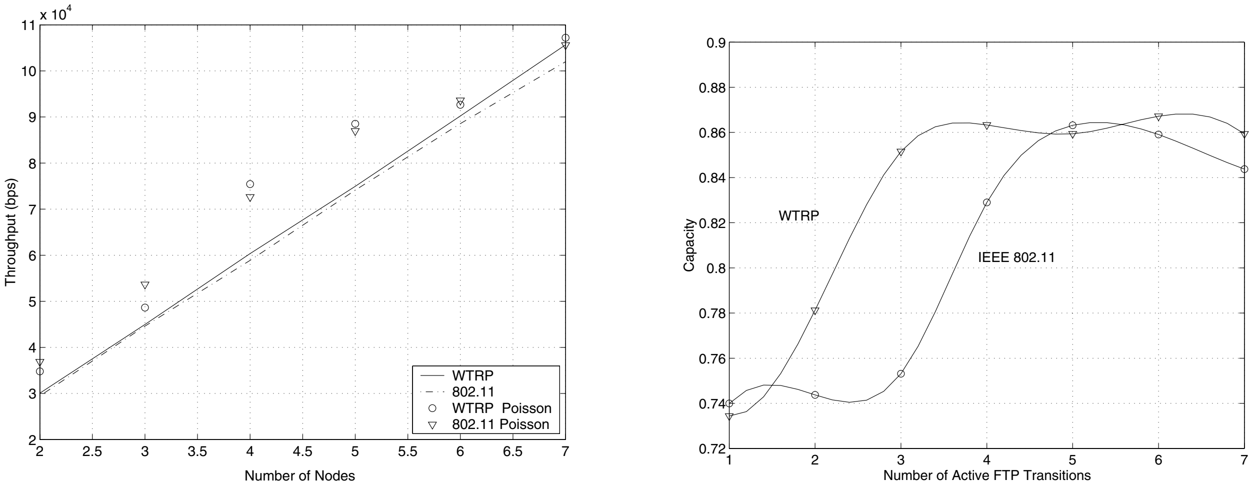

(a) CBR Performance

(b) FTP Performance

Figure 8. Number of Nodes vs Throughput

5 Conclusion

Wireless Token Ring Protocol (WTRP) is presented and compared with IEEE 802.11. WTRP has desirable properties. It achieves high medium utilization since the collision probability is reduced by scheduling the transmission with token reception. WTRP distributes throughput in a flexible and fair manner among stations because each station in the ring takes turn to transmit and is forced to give up the right to transmit after a fixed time. This bounds medium-access time.

Performance results show superior performance for WTRP since it is advantageous by reducing collision probability, by distributing the resource fairly and by achieving high bandwidth utilization due to non random behavior. To bound the medium access latency is also one of the key feature of WTRP that is crucial for real time applications.

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