Evaluation and Comparison of WTRP and CSMA/CA Protocols in Ad hoc networks

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ABSTRACT:
Channel sharing strategy through Media Access Control (MAC) protocols for avoiding collision is a challenging issue in Ad hoc networks. Deploying two distinct approaches, Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) and Wireless Token Ring Protocol (WTRP) play pivotal roles in MAC sublayer management. These protocols have been used in a variety of networks ranging from Internet of Things (IoT) to low rate tactical links in High Frequency (HF) band. In this paper, we investigate the operational algorithms of CSMA/CA and WTRP protocols and compare them via simulation in NS-3 simulator. The two protocols are evaluated and the appropriate protocol in terms of delay and throughput is chosen for networks with varying load, which is affected by node and packet number. Our results show that in networks with light load where high throughput is warrantied, CSMA/CA outperforms WTRP in terms of delay. However, algorithm of WTRP leads to higher throughput in networks with heavy traffic.

KEYWORDS: MAC protocol, Carrier Sense, Token Ring, WTRP, NS-3.

1. INTRODUCTION

To improve flexibility and performance in wireless networks, more and more ad Hoc structure is being applied. In these networks, each node is responsible to help in network management. Frequency bandwidth as a limited resource leads us to share a common channel between multiple nodes to use it for data transferring. Media Access Control (MAC) is being used to provide a mechanism to prevent collision in wireless common channel. Contention base and contention free are two approaches to design MAC protocols. In contention base, each node competes to access channel and use it. In contrast, the nodes can reach to channel without competition for a limited period. Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) and Wireless Token Ring Protocol (WTRP) are two kinds of this approaches respectively. Since the presence of the MAC protocol and its mechanism to control common channel effects on throughput and mean delay which are two criterions in quality of service (QoS), we decided to compare them in technical scenarios and reveal appropriate protocol in heavy and light traffic which is totally affected by node and packet number in network.

Many researches have been done in recent years about performance considerations of MAC protocols. In [1] M. Anwar et al proposed a technique for making IEEE 802.15.4 standard suitable for low-latency deterministic networks. The proposed technique employs Time Division Multiple Access (TDMA) mac protocol in star topology. They showed that TDMA as a contention free protocol can eliminates the risk of frame collisions largely; medium-access control sublayer modifications reduce the non-determinism of the network and increase the bandwidth efficiency.

Eric Johnson et al [2] made a comparison between Token Ring, TDMA, Distributed Coordination Function (DCF) and Distributed Coordination for High Frequency (DCHF) with their mathematically considerations. They took account of turnaround time as an important metric in long-range communications like HF tactical link. Mustafa Ergen et al introduced the structure of WTRP protocol in [3] and they simulated WTRP based on 802.11 and had a brief analysis on their results in [4]. In despite of our work, in [4], [5] WTRP was conducted over DCF operation in 802.11. Zhenhua Deng et al introduced an enhanced WTRP based on 802.11 in [6]. They used tree additional mechanism integrated to WTRP which leads to better throughput. In [7] WTRP was used as the MAC protocol in Internet of Things (IoT). Yuangua Bi et al used WTRP in multi-channel structure for Intelligent Transport System (ITS) where token frames could be transmitted freely in separated channels with data frames. Ray Guang Cheng et al tried to solve channel access problem by nodes in dense networks [8]. They explained that subnetworks can be taken from a dense network and token ring algorithm can be used as MAC protocol. They showed that stable QoS could be achievable by token ring presence in MAC sublayer. In [9] token ring in IoT

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network has been used and its performance for one and two hop relay in physical layer is considered. The results show that by dividing network to some connected subnetworks, the increase in the number of nodes could not have a considerable effect on token ring performance to reduce QoS. Khalid EL Gholami et al used 6LoWPAN over IEEE 802.15.4 to use IPV6 in NS-3 simulator as a reliable choice Internet/ web of Things (I/WoT) [10]. They believed that this WPAN work could be seen as the foundation for future I/WoT simulation on NS-3. WTRP as a MAC protocol for vehicular Ad hoc Networks (VANETs) is purposed in [11]. It is shown that bounded latency and reserved bandwidth of WTRP can guarantee the QoS in mesh topologies. In [12] CSMA is used as the MAC protocol for WSNs and has been tried to reduce energy consumption caused by collisions from weak signals based on WIMAX framework in OMNET++. Sunil Kumar et al prepared a survey for MAC protocols on ad hoc networks and had a brief explanation on various protocols [13].

In our work, different from the previous works, we investigate WTRP beside CSMA for the IoT applications to compare their performance in signaling overhead, hidden terminal and QoS considerations. Unlike the other works especially in [4], [5] which WTRP has been used with DCF signaling, we totally implement it as a unique MAC protocol in NS-3 as an open source powerful network simulator. To have a practical point of view and define technical scenarios, we considered the 6LowPAN structure on IEEE 802.15.14 module in NS-3. At first, we have done our simulation by CSMA/CA MAC protocol in this module, and then we implement WTRP mechanism as a new MAC protocol in it. We consider various situations for 6LowPAN and show that which of these two protocols deliver better performance in each situation. The remainder of the paper is organized as follows. An overview on CSMA/CA and WTRP is done in section 2. Section 3 presents the results of simulations and analysis the aspects of them based on 802.15.4 module in NS-3. Conclusions are finally drawn in section 4.

2. TECHNICAL OWERVIEW

In this section, CSMA/CA as a contention base and WTRP as a contention free MAC protocols are being studied.

2.1. CSMA/CA

Consider a limited bandwidth as a common channel; we can sense its existing energy by a connected modem to determine whether there is a signal or not with a threshold level. Existence of a signal higher than this threshold implies that a node is deploying the channel and lower than that means that only noise exists in the channel and the channel can be assumed free. Hence, we are allowed to send data through channel. This approach is used in CSMA algorithm to sense and use the channel. In wireless channels to avoid collisions caused by Hidden Terminal, DCF protocol with RTS and CTS can be employed, as in IEEE 802.11 standard.

In wireless ad hoc networks based on IEEE 802.15.4 framework, we can find CSMA with carrier Assessment (CA) without RTS/CTS frames. It means that WPAN uses simple sensing strategy as CSMA/CA. There are two kinds of slotted (GTS) and Unslotted CSMA/CA protocols in WPAN and we use Unslotted CSMA/CA in NS-3 for our purpose. After receiving packet from upper layer in LLC sublayer and generating DPDU frame, LLC requests CSMA/CA to check channel to give us permission to send DPDU. If the channel is free, we can deliver DPDU to the modern in order to send it via channel. In contrast, DPDU reserve in LLC and we wait for a Back Off Binary period and sense the channel again. Practically, after 3~5 attempts to send via channel sensing and failing, we must drop the packet inside the DPDU frame which leads to decrease QoS. Equation (1) shows Back Off Binary time based on IEEE 802.15.4.

$$Back\ off\ \ Binary = 2^{BE} - 1. \tag{1}$$

in where $BE = 0 \sim 8$ and it controls increasing waiting time. In WPAN standard recommendations, BE is considered as (2) because of Low-Range operational.

$$\begin{aligned} BE_{max} &= 3 \sim 8. \\ BE_{min} &= 0 \sim 3. \end{aligned} \tag{2}$$

The maximum number of considering Back Off trying is as (3).

$$\text{Maximum Back off try} = 0 \sim 5. \tag{3}$$

In NS-3 simulator, this parameter is set to 4 as default. This parameter determines the number of attempts to access the channel for each node, via CSMA/CA. Fig.1 illustrates this algorithm.

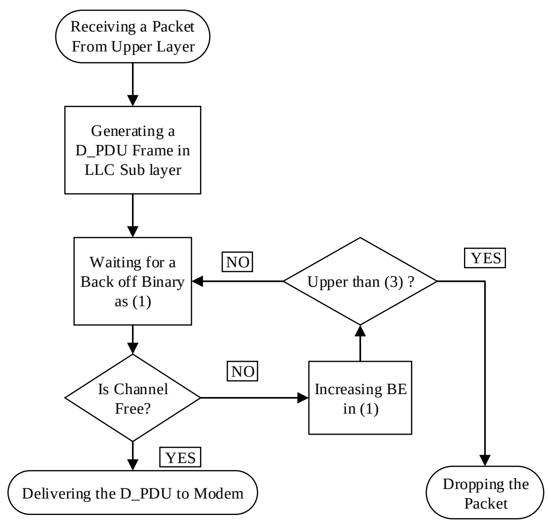


Fig. 1. Trying to access channel by a node in CSMA/CA protocol

Therefore, if we consider (1) and (2), we can meet CSMA/CA as an on demand MAC protocol. Because, if a node does not have a packet to send, we do not need to sense channel. Please consider Fig 2. If node 1 wants to send its DPDU frame, it senses the channel and prevents sending, because another node (Node 3) is using the channel. Fig. 2(a) and (b) show these concepts.

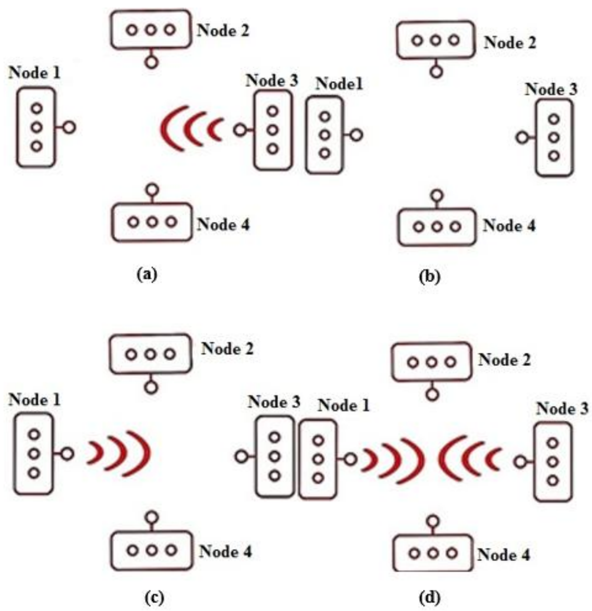


Fig. 2. (a) Carrier sensing by a node to check channel, **(b)** Checking Channel , **(c)** Data transmission by node 1, **(d)** Interference in channel caused by unsuccessful carrier sensing by node 1

After a while based on Back Off Binary Periods, node 1 finds the channel free and sends its DPDU via it. Fig. 2(c) shows this operation. If a node decides to send a frame to channel simultaneous with another node based on incomplete sensing, it evidently leads to collision. Fig. 2(d) demonstrates this collision. Due to not using control signaling with the purpose of reduction of the overhead and solely applying carrier sensing, the CSMA/CA used in 6LowPAN is not to be able to deal with the hidden node problem and it is one of the challenges in Ad hoc networks which needs considerable attention.

2.2. WTRP

As mentioned previously, we consider token passing algorithm to control channel access based on the contention free approach. Token is a MAC frame as MPDU, which has multiple types. One of them is the right to transmission (RTT) which passes between the nodes in network. Any node that owns the RTT can use the channel to transfer DPDU and if it does not any DPDUs, it must send the RTT to its successor in network. Therefore, the other nodes, which do not have the RTT, remain quiet and do not send anything to the channel [5]. Hence, WTRP can overcome hidden node problem using its signaling frames. Ring is a conceptual topology to help us imagine token passing and our network can be accomplished in any voluntary topology. It can be concluded that if the token passes among nodes without any problem, there is no collision in the network. Fig. 3 shows token passing among nodes.

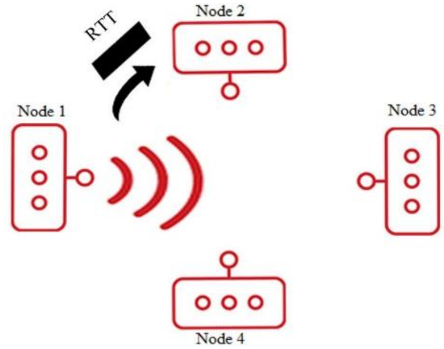


Fig. 3. RTT token is passing between the nodes in channel

Please consider Fig. 4(a). A packet is received from upper layer and it is ready to send as a DPDU frame in node 4. Because of RTT absence, node 4 reserves DPDU and do not send it through channel. When node 4 receives RTT from the channel, it holds this frame and delivers DPDU to the modem in order to send it via channel. After this Data transmission, RTT will be sent to the successor, which is node 1. Fig. 4 (b) shows this operation.

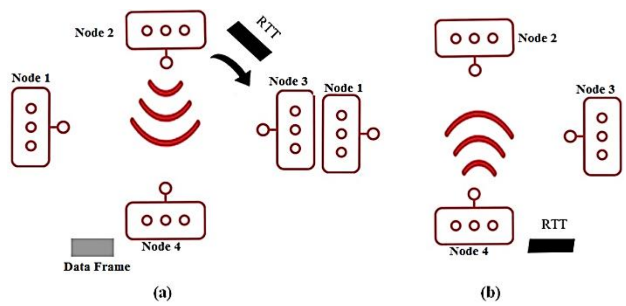


Fig. 4. (a) Preventing to send data due to lack of permission, **(b)** Holding RTT and sending data in free channel

As we mentioned WTRP has overhead signaling frames. In [5], the general M-PDU frame for WTRP is purposed which is shown in Fig. 5 (the lengths are mentioned in Byte).

FC	RA	DA	SA	NON	GSN	SN
1	6	6	6	2	4	4

Fig. 5. Management frame for WTRP

In the frame control (FC) field, frame type like RTT should be determined. Ring Address (RA) is the address of the Ring owner node who has generated the

Ring as the first member, with other nodes joining it afterwards. DA and SA are destination and source address fields respectively. Number of nodes (NON) determines the number of active nodes in network. Generation sequence number (GSN) and sequence number (SN) is counters that increment whenever RTT passes from the Ring owner and each node respectively. This frame is an overhead, which is always circulated in network. So channel is always busy and in contrast with CSMA/CA, this protocol has more complexity in implementation. Algorithm of WTRP to control and manage data transmission via channel is illustrated in Fig. 6.

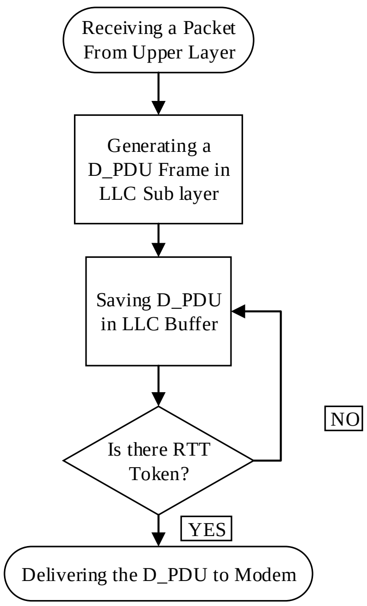


Fig. 6. Managing data transmission in channel by WTRP

As we know, token passing creates a perpetual delay in network to handshake token between the nodes which is its signaling procedure, so we expect that delay be additive as the number of nodes increases. On the other hand, due to prevention of multiple attempts to access, the channel and reduction in the number of dropped packets, better QoS will be promised, especially under heavy load in a dense network.

3. PERFORMANCE COMPARISON OF CSMA/CA AND WTRP PROTOCOLS

In order to compare the two protocols, we have deployed NS-3 simulator, an open source Linux-based software and a discrete event simulator (DES). IEEE 802.15.4 module with CSMA/CA as its default MAC protocol will be primarily used, which will be then substituted by WTRP to have a similar condition for both protocols. Node entrance and exit is taken into account and “RandomTreeWalk” model is used for mobility of the nodes. This model puts the nodes in our predefined positions and after running simulation they move randomly in a limited area. Whether in terms of practicality and hardware feature and NS-3 simulator point of view, we can save our DPDUs in LLC sublayer for a while, but for creating a hard practical situation for WTRP, we drop packets after a specific number of trying to send after checking RTT. We define a counter, which increments after each RTT check. If it reaches to a maximum number (we define it as 8), we will drop that queued packet. Fig. 7 illustrates this algorithm.

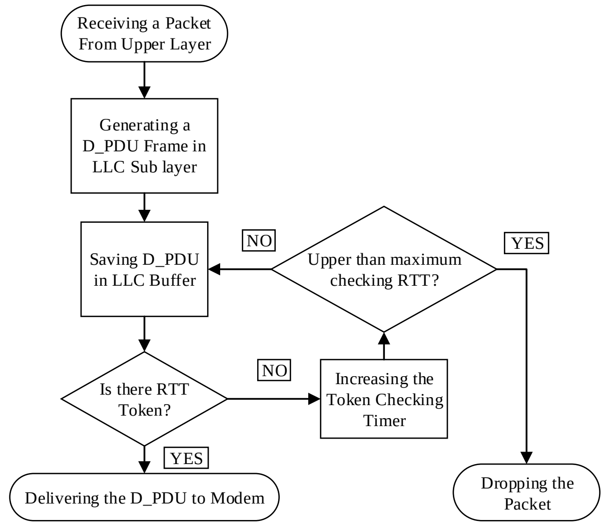


Fig. 7. Dropping the packet in frame after passing maximum RTT checking

3.1. Metrics

Before analyzing the simulation results, we introduce our evaluation metrics based on NS-3 recommendations in (4) -(7) as below:

$$Throughput = \frac{8 \times Total\ \ Packets \times Packet\ \ Size}{Simulation\ Time}. \quad (4)$$

$$Mean\ \ Delay = \frac{Sum\ of\ \ Delays}{Number\ of\ \ Flows}. \quad (5)$$

$$PLR = q = \frac{LostPackets}{RxPackets + LostPackets}. \quad (6)$$

$$PDR = 1 - PLR \approx 1 - q. \quad (7)$$

Throughput is the number of packets (in Byte) which arrive at their destination nodes successfully measured in bits per second. As is stated in (4), throughput is the total number bits transmitted in a defined time interval as simulation time. Mean delay of each simulation can be calculated by (5) with respect to all traffic flows. Packet Loss Ratio (PLR), described in (6), shows the ratio between the number of lost packets and the total number of packets in flows. Packet Delivery Ratio (PDR) as (7) complements PLR too.

3.2. Simulation

In the first scenario, we want to evaluate the effect of increasing the number of nodes on the QoS criteria’s for CSMA/CA and WTRP without congestion. It means that the nodes do not send their

PDUs in same time. It is necessary to mention that our results are average of five times run. Table 1 shows the first scenario summary.

Table. 1. Properties of the first scenario in simulations

Number of nodes	5
Number of packets	5 ~ 40
Packet size	250 byte
Transmission strategy	in 1 second steps without congestion

Fig. 8(a) shows mean delay and Fig. 8(b) shows the throughput of network for five nodes in terms of number of packets as. As expected, without congestion and under light traffic, WTRP has a higher delay, which is affected by token frame overhead. This verified that WTRP with its signaling overhead has more delay in light traffic compared to CSMA/CA. In this scenario, because all of the packets are received at their destination, PLR is 0% and PDR is 100% based on (6) and (7) respectively. In second scenario, we repeat properties based on Table 1 with congestion. It means that all nodes send their PDUs simultaneously.

Fig. 8(c) shows mean delay and Fig. 8(d) shows throughput for this scenario. As we can see, increasing number of packets does not have a particular effect in operation of WTRP and each node waits to get RTT from channel. Nevertheless, in CSMA/CA, a node takes channel for a while and the others complete their trying to reach it and then drop their packets cause by unsuccessful Channel acquisition. So, CSMA/CA based on fig. 8(c) and (d) has more delay and lower throughput in congestion situation. CSMA/CA could not deal with hidden terminal problem in our random moving scenario but WTRP could solve it with its signaling overhead. Therefore, unfair channel sharing in contention base approach has weakness in congestion and large static traffic. This concept effects on packet delivering. Fig. 9(a) and 9(b) show PLR and PDR for this scenario respectively. WTRP could deliver more packets and also preserve QoS in network. So we can sense this concept that using signaling overhead to control the nodes accessibility can be helpful in managing network. However, this overhead can increase delay in light traffic. In the third scenario, we want to evaluate the effect of increasing the number of nodes on QoS criteria's for CSMA/CA and WTRP. Table 2 shows a summery on the third scenario under no congestion situation.

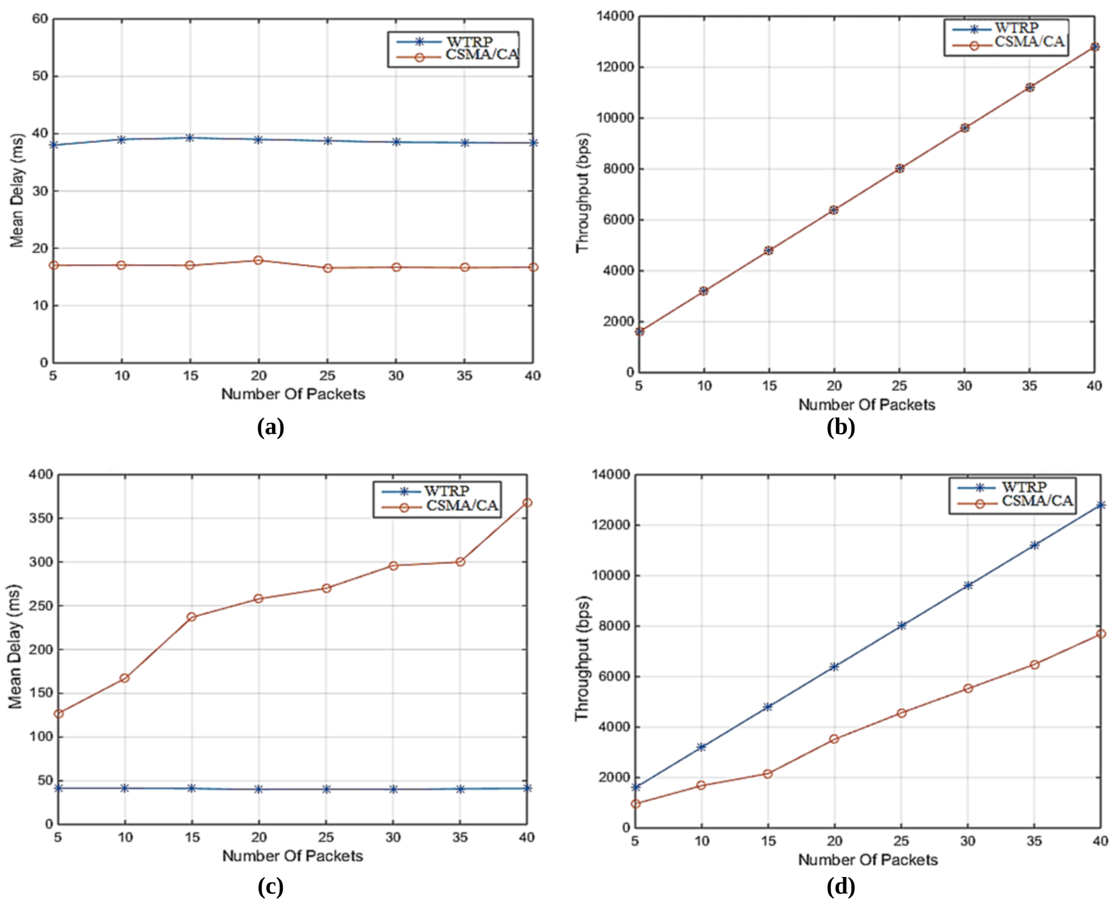
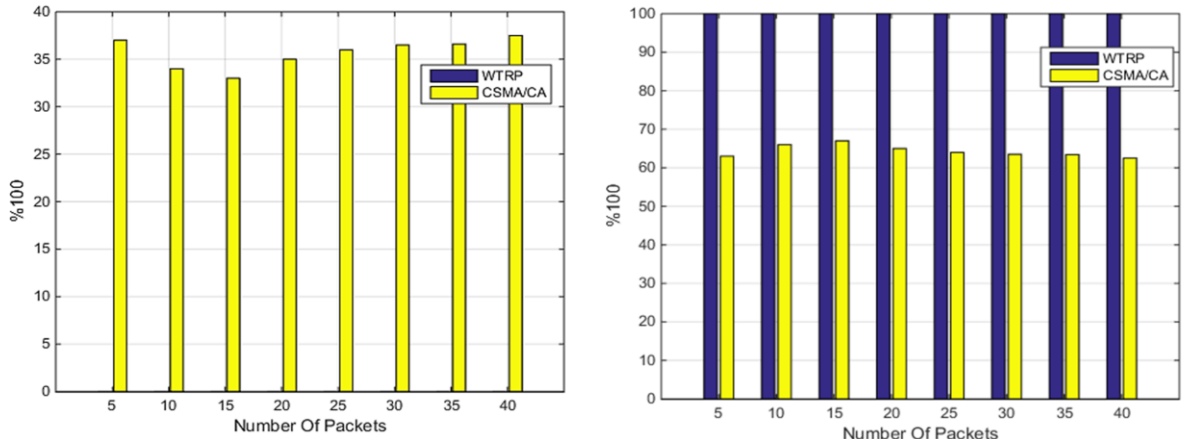


Fig. 8. Performance of the network versus the number of packets: **(a)** Mean Delay and **(b)** Throughput without congestion, **(c)** Mean Delay and **(d)** Throughput with congestion.



(a) (b)

Fig. 9. (a) PLR and **(b)** PDR versus the number of packets with congestion

Table. 2. Properties of the third scenario in simulations

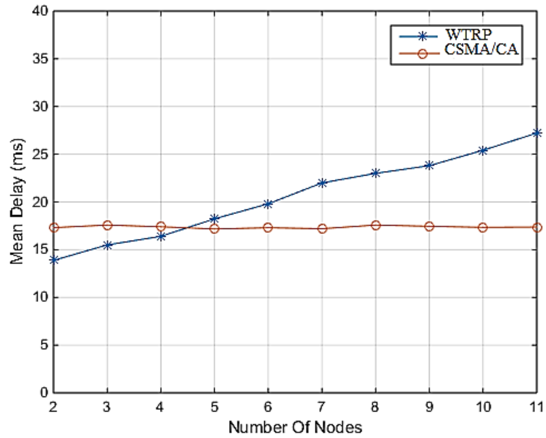
Number of nodes	2 ~ 11
Number of packets	10
Packet size	250 byte
Transmission strategy	in 1 second steps without congestion

Mean delay is illustrated in Fig. 10(a) in terms of number of nodes. With increase of nodes, we can see higher delay in WTRP especially after five nodes. It means that the inherent delay of WTRP cause by overhead signaling will be more effective with increasing number of nodes. Handshaking of signaling overhead in WTRP can be a challenge in dense networks with burst traffic. Despite the use of CSMA/CA protocol with mobility of the nodes and hidden terminal problem, but we can see lower delay than WTRP which it must recover RTT when it lost in movements and also an additional delay must be considered in WTRP by entrance and exit of the nodes. Fig. 10(b) shows throughput for third scenario in terms of number of nodes. Because of light traffic and no congestion, all of the packets could reach to their destinations by both of these protocols and their throughput is similar to each other. So, in a comparative point of view, CSMA/CA is better than WTRP in terms of mean delay. Based on traffic dispensation in no congestion situation in network, all the packets transmitted completely in both protocols. So as same as the first scenario, PLR and PDR are %0 and %100 respectively. In fourth scenario, we repeated Table 2 in congestion condition. Fig. 10(c) and 10(d) show mean delay and throughput for this scenario in terms of number of nodes respectively. As we expected, in heavy traffic and congestion with static traffic distribution, CSMA/CA decrease QoS criteria cause by more try and more failure channel access.

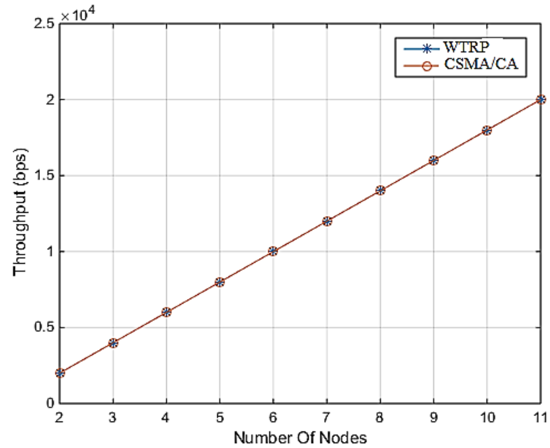
So many packets must wait in queue and we have an exponential increasing delay number of nodes. However, most packets in WTRP are delivered with an appropriate delay to their destinations and we can find that WTRP could deliver more packets than CSMA/CA in a specific duration. Therefore, WTRP outperforms CSMA/CA under heavy traffic. Based on this concept we can consider Fig. 11(a) and 11(b) which show PLR and PDR in terms of number of nodes respectively. As we can see WTRP has a better response in PLR and PDR than CSMA/CA.

Therefore, according to our results we can conclude MAC protocol selection in some points:

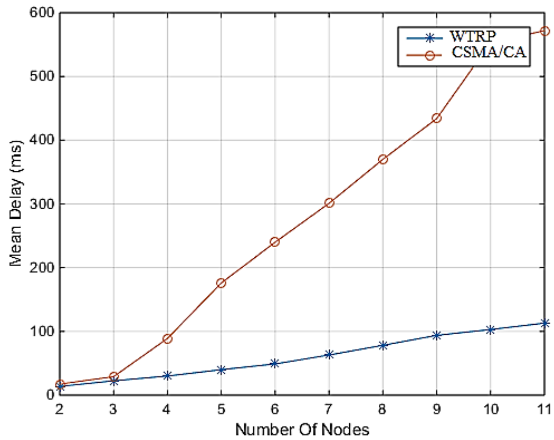
- If we have a network with burst traffic a contention base approach like CAMA/CA can be helpful to have a smaller mean delay. By default, we can warrantee high throughput in this networks and delay is intended criteria of QoS.
- In contrast, in heavy traffic with static and nonstop traffic generation, we have congestion inevitably. In this condition, throughput is our criteria of QoS, which must be considered. Therefore, if we use a contention free protocol like WTRP to avoid unreasonable efforts to access channel and drop our packets, we can use channel with a suitable delay and deliver our packets completely. So, WTRP is a perfect choice.
- As we see in our simulations CSMA/CA cannot deal with hidden terminal problem. But WTRP with its signaling overhead and RTT handshaking based in fig. 6 can solve this problem.
- As observed in our results, complexity and using signaling overhead in WTRP is more than CSMA/CA. So, in simple and thin networks it can be better t use CSMA/CA.



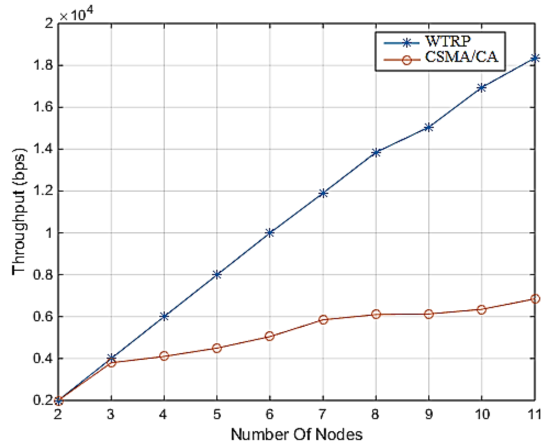
(a)



(b)

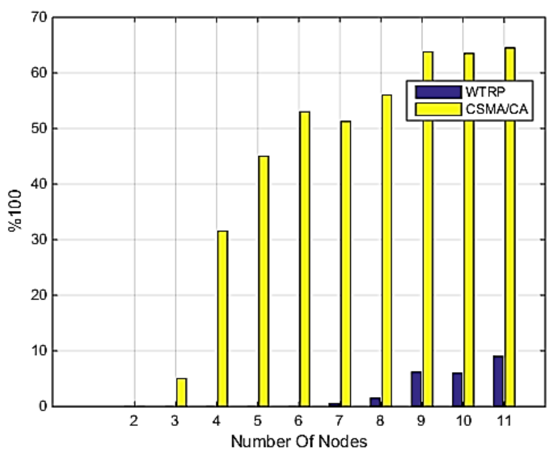


(c)

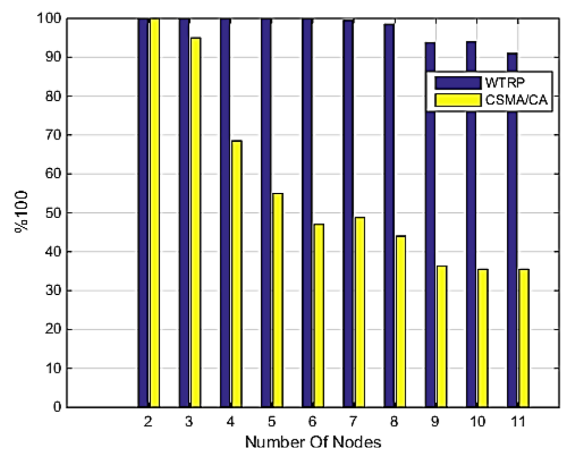


(d)

Fig. 10. Performance of the network versus the number of nods: **(a)** Mean Delay and **(b)** Throughput without congestion, **(c)** Mean Delay and **(d)** Throughput with congestion.



(a)



(b)

Fig. 11. (a) PLR and **(b)** PDR versus the number of nodes with congestion

4. CONCLUSION

In this paper, we had an evaluation and comparison between CSMA/CA and WTRP protocols as examples of contention-based and contention-free approaches in MAC sublayer for IoT networks. We used IEEE 802.15.4 module with 6LowPAN framework in NS-3 simulator. CSMA/CA without signaling overhead and lower complexity could not deal with hidden terminal problem whereas WTRP could solve this problem by using its signaling control frames. Our results showed that in networks with light load where high throughput is warrantied, CSMA/CA outperforms WTRP in terms of delay. However, management of WTRP leads to higher throughput in networks with heavy traffic. So, we could choose them based on traffic shape and number of nodes on network. In dense networks with light load CSMA/CA has lower delay and in dense and static traffic WTRP could be a suitable choice to be used as MAC sublayer protocol.

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