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Traffic Class Prioritization-Based Slotted-CSMA/CA for IEEE 802.15.4 MAC in Intra-WBANs

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Abstract

In this paper about the proposes an improved Traffic Class Prioritization based Carrier Sense Multiple Access/Collision Avoidance scheme for prioritized channel access to heterogeneous-natured Bio-Medical Sensor Nodes for IEEE 802.15.4 Medium Access Control (MAC) in intra-Wireless Body Area Networks.

The prioritized channel also access is achieved by assigning a distinct, minimized and prioritized back off period range to every traffic class in every back off during contention. And the TCP-CSMA/CA, the BMSNs are distributed among four traffic classes based on the existing patient's data classification. Five moderately designed backoff period ranges are proposed to work a distinct, minimized, and prioritized backoff period range to each traffic class in every backoff during contention.
The produce results prove that the proposed TCP-CSMA/CA scheme performs best than the IEEE 802.15.4 based PLA-MAC, eMC-MAC, and PG-MAC as it achieves a 47% also decrease in the packet delivery delay and a 63% is increase in the PDR.

Introduction:

Wireless Body Area Networks provide unsupervised, inconspicuous and real-time continuous health monitoring and they are used in various applications, such as medical, personal healthcare, consumer electronics, military, sports and fitness, entertainment and rehabilitation systems. WBANs create advancement in human healthcare by offering proactive management and early diagnosis of various diseases cases. The ill patient's vital-signs data are collected and analyzed by deploying on them.
These BMSNs are responsible for sending the sensory vital-signs information to the local base station known as Body Coordinator, located and keep on near the human body. The MAC layer also plays an important role to get high performance Conventionally; some of the existing beacon-enabled MAC protocols for WBANs use standard slotted-Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) scheme of IEEE 802.15.4 for contention to access the channel. In slotted-CSMA/CA, each BMSN delays for a random number of backoff periods and this random number is selected from the backoff period range in each backoff during contention for channel access in the Contention Access Period (CAP).

Related Work

The IEEE 802.15.4 not provide of any criterion for prioritized channel access to the heterogeneous-natured BMSNs. Different IEEE 802.15.4 based MAC schemes have been proposed for traffic prioritization. Among them include the following:

In all. Provide traffic prioritization for diverse traffic types with specific Quality of Service requirements through preemptive channel allocation and non-preemptive data transmission in the allocated channels. The authors distribute the traffic into three classes. We can say for the Every class

BMSN selects the random backoff number from the backoff period range 0 To 2^{BE} (Class + 1) − 1, where Class is the traffic class value. However, every backoff period range starts from zero which

Can result in the prior channel access to the low priority BMSN and then to the high priority BMSN. Moreover, the backoff period range of high priority class is repetitively used in the backoff period range of low priority traffic class which also can cause non-prioritized channel access. And more the same backoff period range is assigned to each traffic class in their third, fourth and fifth backoffs which increases collision and packet loss rate. In addition, a high backoff period range is assigned to low priority traffic classes in the third, fourth and fifth backoffs delaying low priority traffic. Introduced traffic Priority and load-aware MAC (PLA-MAC) scheme for WBANs to provide contention-based traffic prioritization with low packet delivery delay and energy consumption.

However, this high transmission delay is not appropriate for medical applications. In addition, all BMSNs use the same backoff period range to select a random backoff number in each backoff; in that case, traffic is not prioritized. Hence, the BMSN with low priority data can easily access the channel before the one with high priority data in any backoff during contention. Priority-aware adaptive slot allocation MAC (PAS-MAC) protocol in WBAN for prioritized channel access to the heterogeneous-natured BMSNs during contention to reduce delay and energy consumption. And finally this scheme is similar to LTA-MAC in terms of traffic prioritization, we can say that it has the same constraints which are already mentioned under the LTA-MAC scheme

finally of Slotted-CSMA/CA Scheme of the Beacon-Enabled Mode of IEEE 802.15.4 MAC

Every BMSN contends for channel access to transmit its packets by using the slotted-CSMA/CA scheme during CAP of the MAC super frame. The slotted-CSMA/CA scheme is used by MAC sublayer for transmissions in beacon-enabled mode. The slotted-CSMA/CA scheme uses three variables.

Number of Backoff, Contention Window, and BE. The NB is the number of backoffs that are required by the CSMA/CA scheme against each transmission attempt, and it initializes to zero at the start of each new transmission attempt. CW is the waiting time.

First standard slotted-CSMA/CA scheme initializes the variables NB = 0 and CW = 2. This slotted-CSMA/CA scheme also uses some constants: macMinBE and aMaxBE. And the macMinBE is the minimum number of backoffs, and its default value is 3 while aMaxBE is the maximum number of backoffs and it is initialized by 5. If battery life extension (BLE) (i.e., used to determine the duration of CAP, which is equivalent to six complete backoff periods, if BLE = true) initializes to true then 2 is assigned to BE, otherwise the value of macMinBE.

Furthermore, the MAC sublayer of BMSN requests the PHY sublayer to perform clear channel assessment (CCA) at the backoff period boundary to ensure collision-free channel access. If the value of CW is not equal to zero, the MAC sub layer of BMSN requests PHY sublayer to perform CCA again at the backoff

Each BMSN performs at most five backoffs to access the channel against each packet. In the first backoff, each BMSN selects a random number from the range [0–7] and completes the backoff period for the selected number of times. In the second backoff, each BMSN selects a random number from the range [0–15]. Likewise, in the third backoff, the selection of a random number is from the range [0–31], which remains unchanged in the fourth and fifth backoffs. However, the use of the same backoff period range by all BMSNs that belong to different TCs in each backoff results in high collisions. The retransmission of collided data packets causes a higher packet delivery delay with low throughput and low energy efficiency.

1. Design of TCP-CSMA/CA Scheme

The backoff process is discussed in detail in the following sub-sections. In addition, each improved backoff of the TCP-CSMA/CA is carried out in the proposed algorithm shown in Algorithm.

1.1. Proposed Backoff Period Ranges for All Backoffs

The proposed TCP-CSMA/CA scheme provides distinct, minimized and prioritized backoff period ranges for all backoffs to solve the problems above by introducing the following equations.

Backoff Period Range used in the first backoff:

$TC\ 2^{(BE+1)}$ To $2^{BE} + 4TC + 1$ (1)

Backoff Period Range used in the second backoff:

$2^{BE}\ (TC + 1)$ To $2^{BE} + 4TC + 3$ (2)

Backoff Period Range used in the third backoff:

$2^{BE}\ (TC + 1) - 4TC$ To $2^{BE} + 4TC + 3$ (3)

Backoff Period Range used in the fourth backoff:

$2^{(BE-1)} + 4(TC + 1)$ To $2^{BE} + 4TC - 1$ (4)

Backoff Period Range used in the fifth backoff:

$2^{(BE-1)} + 4TC$ To $2^{(BE-1)} + 4TC + 3$

need to be delivered within a specific time-frame, e.g., EEG and , reliability traffic class for BMSNs with reliability data packets (should be delivered with minimum losses but not within specific time-frame e.g., HR and RR), delay traffic class for BMSNs with delay data packets (can tolerate some losses but need to be delivered within specific time-frame e.g., telemedicine video imaging) and non-constrained traffic class for BMSNs with non-constrained data packets (can tolerate losses and do not have any time-constraint e.g., BP and temperature).

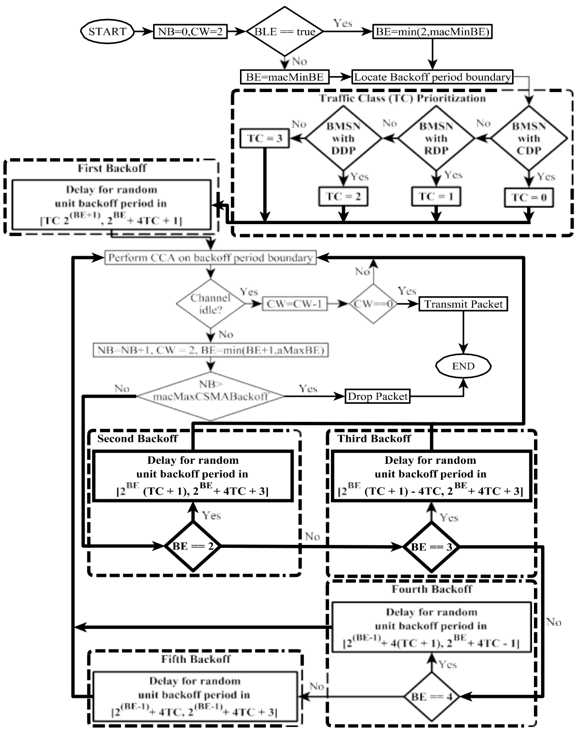
TC	Priority	Classification of BMSNs	Traffic Class
0	first	BMSNs with CDPs	Critical Traffic Class (CTC)
1	second	BMSNs with RDPs	Reliability Traffic Class (RTC)
2	third	BMSNs with DDPs	Delay Traffic Class (DTC)
3	fourth	BMSNs with NDPs	Non-constrained Traffic Class (NTC)

Table 1. Traffic Class Prioritization.

1.1.2 Backoff Process

The contention is distributed among five backoffs. In Figure1, TCP-CSMA/CA scheme initializes the variables NB to 0 and CW to 2. It also uses constants; macMinBE and aMaxBE to represent the minimum and the maximum number of backoffs respectively. The value of macMinBE is 1 and the value of aMaxBE is 5. Then, the BMSN verifies that the value of BLE is either true or false. In TCP-CSMA/CA scheme, BLE is initialized to false. The variable BE is initialized to value 1. Afterwards, the MAC sublayer of the BMSN locates the next backoff period boundary. It further verifies whether BMSN is with CDP or not. If it is, then 0 is assigned to its TC. Otherwise, it verifies whether BMSN is with RDP or not. If it is, then 1 is assigned to its TC. However, if BMSN is with DDP, then 2 is assigned to its TC. Otherwise, 3 is assigned to its TC.

Figure 1. Flowchart of Traffic Class Prioritization based Carrier Sense Multiple Access/Collision Avoidance (TCP-CSMA/CA) scheme. The dotted blocks show the contributions made to assign a distinct, minimized, and prioritized backoff period range to each traffic class in every backoff.



1.1. Algorithm for TCP-CSMA/CA Scheme

The following algorithm for the proposed TCP-CSMA/CA scheme is presented in Algorithm 1. The algorithm assigns the distinct, minimized, and prioritized backoff period ranges to each traffic class in every backoff. Therefore, each traffic class accesses the channel on a priority basis and in the end.

Hence, the performance of TCP-CSMA/CA scheme is improved in terms of packet delivery delay, PDR, throughput, and energy consumption. The detailed description of TCP-CSMA/CA scheme is in Section.

Algorithm 1: TCP-CSMA/CA: Traffic Class Prioritization-based slotted-CSMA/CA
Notations
BE: Backoff Exponent NB: Number of Backoffs
CW: Contention Window Size BLE: Battery Life Extension CCA: Clear Channel Assessment
Mac MinBE: A constant that represents minimum value of BE aMaxBE: A constant that represents the maximum value of BE TC: Traffic Class
MacMa xCSMA Backoff: A constant that specifies the limitation of the number of backoffs
Input
NB = 0, CW = 2, BLE = 0, BMSN_i, CCA = 2, macMinBE = 1, aMaxBE = 5, macMaxCSMABackoff = 4
Process

Set CW=2, NB=0
if (BLE == true) **then**
Set BE ← min (2, macMinBE) [step 1]
GOTO [step 2]
else
Set BE ← macMinBE
GOTO [step 2]
end if
Locate Backoff period boundary [step 2]
if (BMSN_i with CDPs == true) **then** [step 3]
Set TC ← 0
GOTO [step 6]
else if (BMSN_i with RDPs == true) **then** [step 4]
Set TC ← 1
GOTO [step 6]
else if (BMSN_i with DDPs == true) **then** [step 5]
Set TC ← 2
GOTO [step 6]
else
Set TC ← 3
GOTO [step 6]
end if
Delay for random unit backoff period in TC 2(BE+1) To 2BE + 4TC + 1 [step 6]
PHY sublayer of BMSN_i performs CCA on backoff period boundary [step 7]
if (CAP_channel == idle) **then**
Set CW ← CW-1 [step 8]
if (CW == 0) **then**
Transmit the packet
else
GOTO [step 7] to perform CCA again
end if
else //when channel is busy
Set CW ← 2, NB ← NB+1, BE ← min (BE+1, aMaxBE) [step 9]
end if
if (NB > macMaxCSMABackoff) **then**
BMSN_i drops the packet and algorithm is terminated with the status of channel access failure
else
if (BE == 2) **then** [step 10]
Delay for random unit backoff period in [2BE (TC + 1) To 2BE + 4TC + 3] [step 11]
GOTO [step 7]
else if (BE == 3) **then** [step 12]
Delay for random unit backoff period in [2BE (TC + 1) − 4TC To 2BE + 4TC + 3] [step 13]
GOTO [step 7]
else if (BE == 4) **then** [step 14]
Delay for random unit backoff period in [2(BE−1) + 4(TC + 1) To 2BE + 4TC − 1] [step 15]

46. **GOTO** [step 7]
47. **else**
48. Delay for random unit backoff period in $2(BE-1) + 4TC$ To $2(BE-1) + 4TC + 3$ [step 16]
49. **GOTO** [step 7]
50. **end if** //end of inner if which works on different values of BE

50. **End if** //end of outer if which checks NB > macMaxCSMABackoff

Output: A decrease in packet collision rate, packet delivery delay, packet loss rate, energy

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5. Performance Evaluation

An extensive simulation was conducted in NS-2 to evaluate the performance of the TCP-CSMA/CA scheme against PLA-MAC [68], eMC-MAC [69], and PG-MAC [71] in terms of average packet delivery delay, throughput, PDR, PLR, and energy consumption. directly connected to the on-body local base station, body coordinator (BC). All the BMSNs were deployed within 3 m around the BC . Each transmitted their observed data packets to the BC using contention to access the channel in the CAP. It was assumed that the BMSNs had limited processing power and energy supply while BC had more processing power and external power supply. The rest of the simulation parameters are shown in Table3.

5.1. Simulation Model

Fourteen heterogeneous-natured BMSNs were deployed on the simulated human body.

5.1. Simulation Results

The performance of the TCP-CSMA/CA scheme is presented in two dimensions. (1) In terms of different number of BMSNs which are varied from 1 to 14, and (2) In terms of various traffic classes of TCP-CSMA/CA conducted with respect to varying time in seconds. The analyses are explained below.

Table 3. Simulation parameters.

Parameter	Value	Parameter	Value
Operating Carrier Frequency	2.4 GHz	Base Slot Duration	60 symbols
Channel Data Rate	250 kbps	Sending Data Rate	62.5 kbps
A Slot Duration	15.36 ms	Beacon Interval Duration	491.52 ms
Super frame Duration	245.76 ms	Inactive Period Duration	245.76 ms
Number of super frame Slots	16	MAC Data Payload	102 bytes
Beacon Order (BO)	5	Max PHY Packet Size	127 bytes
super frame Order (SO)	4	Turnaround Time	12 symbols
a CCA Time	8 symbols	UnitBackoffPeriod	20 symbols
Max Frame Retries	3	macAckWaitDuration	55
Number of nodes	14	Body Coordinator	1
Minimum BE	1	Maximum BE	5
Battery Life Extension (BLE)	False	Synchronization Mode	Beacon-Enabled
Traffic Type	CBR	Initial Power	100 W
MaxCSMABackoffs	4	Power Consumed in Transmission state	0.027–0.22 W
Power Consumed in the Reception state	0.0018 W	Power Consumed during Transition	0.0004 W
Power consumed in a Sleep state	0.000005 W	Time Required for Transition	0.0008 s
Simulation Time	2000 s	Topology	Star

Similarly, in Figure2, PG-MAC scheme uses a D $_{type}$ variable instead of BE to calculate backoff period range. Therefore, each traffic class uses only one backoff period range, which remains unchanged in all backoffs, leading to the high collision and degradation of performance due to the retransmission of collided data packets. Thus, PG-MAC shows higher delay after the fourth BMSN which increases gradually after 7th BMSN. The proposed TCP-CSMA/CA observes the lowest average packet delivery delay. The reason is that each traffic class gets a distinct, minimized, and prioritized backoff period range in every backoff. Even in the last backoff, the upper limit of the backoff period range for lowest TC is 31, which also reduces the packet delivery delay of the BMSNs belonging to the lowest level TC. Thus, the TCP-CSMA/CA scheme reduces the average packet delivery delay and attains improvement of 58%, 23%, and 59% as compared to the PLA-MAC, eMC-MAC, and PG-MAC schemes, respectively

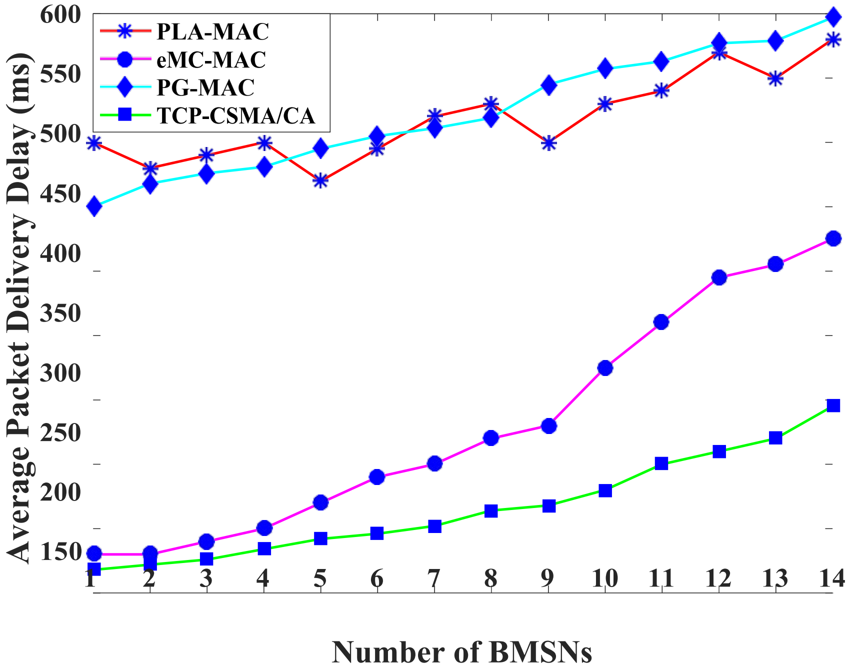
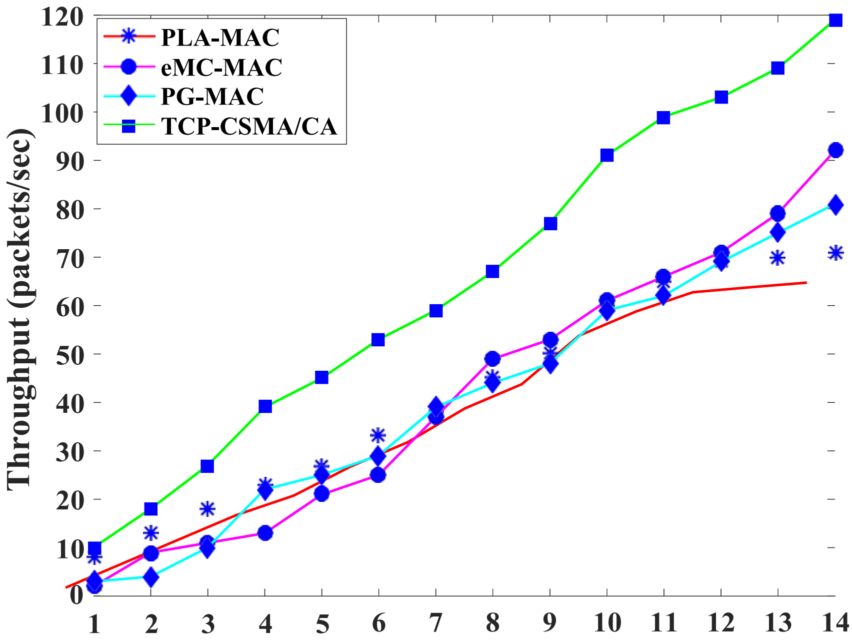


Figure 2. Average packet delivery delay versus number of BMSNs.

Figure3 exhibits the throughput comparison of TCP-CSMA/CA scheme with the benchmarked MAC schemes. In PLA-MAC, the BMSNs with DPs and OPs use a high backoff period range. Therefore, the throughput of the PLA-MAC decreases gradually. In PLA-MAC, a distinct backoff period range assigns to each traffic class in the first backoff whose range remains unchanged until the last backoff. However, this repetitive assignment of the same backoff period range in all backoffs increases collision which results in more retransmission , thereby, reducing the overall throughput of PLA-MAC. Similarly, in eMC-MAC, the lower priority traffic classes get higher backoff period ranges resulting in the degradation of the throughput prioritized backoff period range to each traffic class in every backoff. The achieved throughputs of TCP-CSMA/CA scheme are 55% compared to PLA-MAC, 56% compared to eMC-MAC, and 61% compared to PG-MAC.



Number of BMSNs

Figure 3. Throughput versus number of BMSNs

Figure 4 presents the packet delivery ratio comparison of the TCP-CSMA/CA scheme with the benchmarked MAC schemes. In PLA-MAC, the overall PDR of the network is 55%. BMSNs numbers 1, 3, 4, 9, and 11 show PDR below 30% as shown in Figure4. As stated earlier, in PLA-MAC, every TC uses the same backoff period range during contention in every backoff which results in increased packet drop rate.

This is due to the repetition of particular backoff period range against every traffic class in each backoff. The proposed TCP-CSMA/CA scheme presents 87% network PDR. Moreover, the BMSNs that belong to different traffic classes show more than 50% PDR. In particular, the fifth BMSN shows 95% PDR, eighth BMSN presents 96% PDR, 11th BMSN achieves 92% PDR, and 14th BMSN has 95% PDR as shown in Figure4 The reason is due to the prioritized, minimized, and distinct backoff period ranges used by each traffic class in every backoff. Hence, the performance of the proposed TCP-CSMA/CA scheme has an improvement of 58% more than PLA-MAC, 50% more than eMC-MAC, and 81% more than PG-MAC in terms of network PDR.

Figure 5 shows a comparative analysis of the TCP-CSMA/CA scheme with the existing benchmarked MAC schemes regarding the packet loss ratio. The PLA-MAC shows 45% netw ork PLR. In particular, the 1st, 3rd, 4th, 9th and 11th BMSNs show PLR more than 70% as shown in Figure5. This high packet loss rate is due to the repetitive use of a particular backoff period range for each traffic class in all backoffs. Similarly, eMC-MAC shows an overall 42% network PLR and 43% BMSNs present PLR above 70% as shown in Figure5. In particular, the first five BMSNs that represent high priority packets show abysmal performance that is more than 70% PLR because they use minimal backoff period range. Furthermore, PG-MAC presents very high PLR, which is the result of repetitive use of the specific backoff period range by each traffic class in every backoff. It is obvious from Figure5that in the TCP-CSMA/CA scheme Comparatively; the energy consumption of BMSNs is reduced in the proposed TCP-CSMA/CA scheme. The TCP-CSMA/CA consumes 70% less energy as compared to PLA-MAC, 59% less than eMC-MAC and 64% less as compared to PG-MAC.

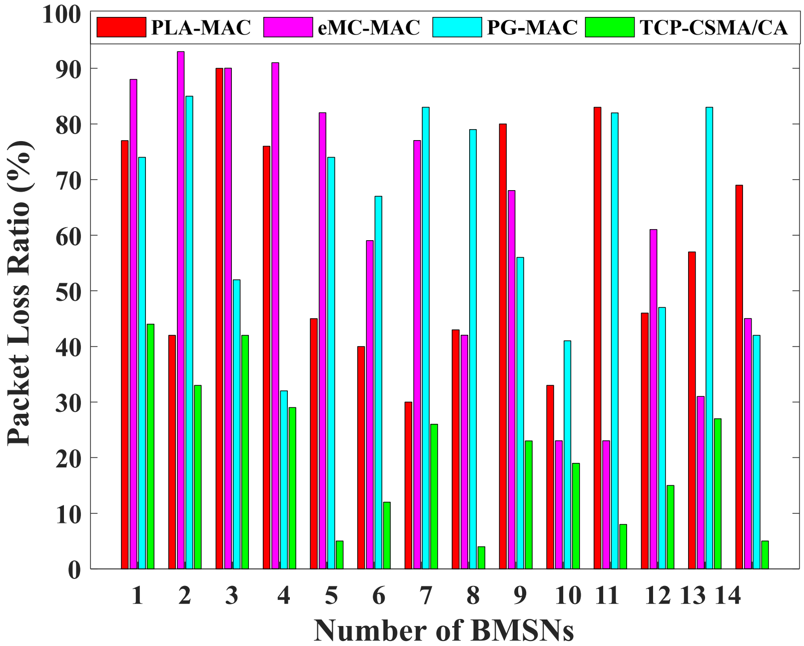
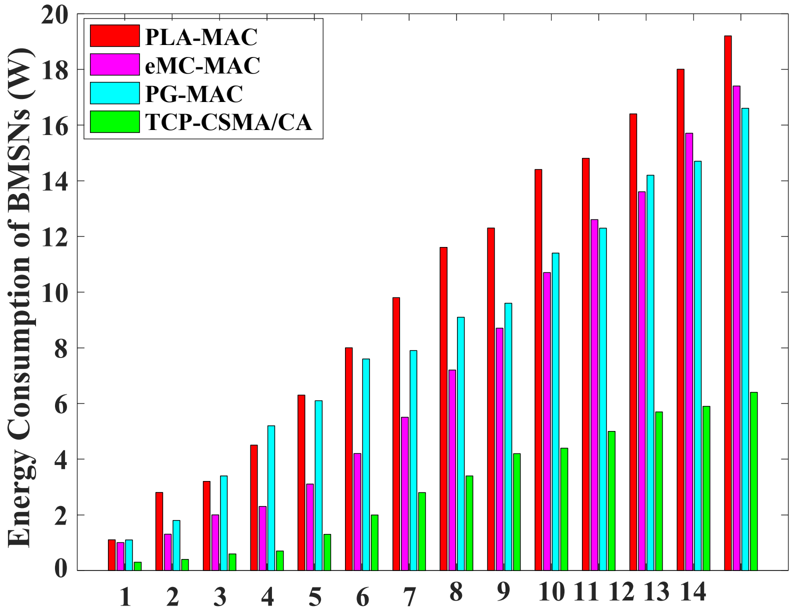


Figure 5. Packet loss ratio versus number of BMSNs.



Number of BMSNs Figure 6.
BMSNs energy consumption versus number of BMSNs.

Comparison among Different Traffic Classes of TCP-CSMA/CA

Figure7exhibits the packet delivery delay comparison among the traffic classes of TCP-CSMA/CA. The CTC shows low packet delivery delay as compared to other traffic classes. This is because TCP-CSMA/CA assigns [0–3] i.e., the lowest backoff period range to CTC in the first backoff. Similarly, TCP-CSMA/CA assigns [4–7] as a backoff period range to RTC in the first backoff. RTC always get distinct and second lowest priority backoff period range in every backoff. Thus, RTC observes a bit more packet delivery delay as compared to CTC. In addition, DTC and NTC have slightly higher packet delivery delay as compared to CTC and RTC. The reason is that BMSNs that belongs to DTC and NTC comparatively get higher backoff period ranges.

Figure8demonstrates the throughput comparison among the traffic classes of TCP-CSMA/CA. The CTC shows comparatively higher throughput. However, in each backoff, the lowest backoff period range is assigned to CTC. As a result, CTC gets the channel access prior to other traffic classes and get more opportunity for data transmission. In a similar way, the second lowest backoff period range is assigned to RTC and thus, achieves second highest throughput. On the other hand, DTC and NTC achieve lower throughput because they get higher backoff period ranges during contention in the CAP.

Figure9presents the packet delivery ratio comparison of traffic classes. CTC achieves highest PDR. The reason is that the highest priority is given to CTC by assigning the lowest backoff period range to CTC. In a similar fashion, RTC, DTC, and NTC achieve the packet delivery ratios according

Figure10shows the packet loss ratio comparison of the various TCP-CSMA/CA traffic classes. CTC has the lowest packet loss rate whereas RTC has higher PLR. The reason is that in every backoff, the backoff period range assigned to CTC is lower than the RTC. Indistinguishably, DTC and NTC observe comparatively higher PLR, since, the higher backoff period is given to these traffic classes in every backoff.

Figure11unveils the energy consumption comparison among different traffic classes of TCP-CSMA/CA. CTC and RTC consume more energy as compared to DTC and NTC. This is because they both get more transmission opportunity. Overall, CTC and RTC attain better performance as

Conclusions

The main goal of the current study was to provide prioritized channel access to heterogeneous-natured BMSNs of different traffic classes with reduced packet delivery delay, packet loss, and energy consumption, and improved throughput and PDR. In summary, the study revealed that the performance of IEEE 802.15.4 based slotted-CSMA/CA decreases by the following issues. When the same backoff period range is assigned to the BMSNs of each traffic class in every backoff during contention, when the BMSNs of each traffic class repetitively use the same backoff period range in its last three backoffs, and when the backoff period range of high priority traffic class is repetitively used in the backoff period range of the low priority traffic class in each backoff. And when the assigned backoff period range in the first backoff remains unchanged in all of the next backoffs. All the above-mentioned issues are resolved by assigning a distinct and prioritized backoff period range to each traffic class in every backoff. Additionally, the assigned backoff period range must also be moderately minimized to provide balanced transmission opportunity to each traffic class. In the future, we plan to enhance the TCP-CSMA/CA scheme based on the CSMA/CA of IEEE 802.15.6 MAC in terms of prioritized channel access for heterogeneous-natured BMSNs to further improve on its performance.

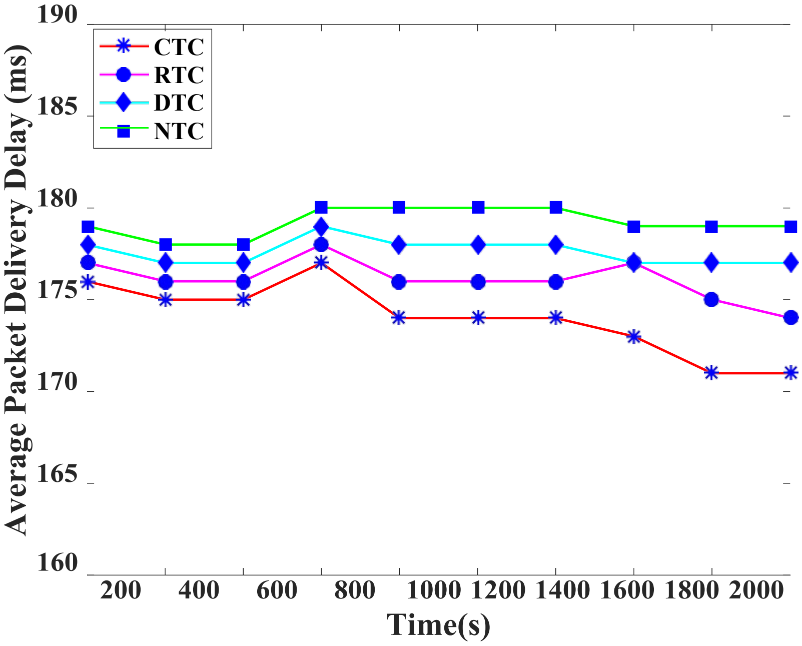


Figure 7. Packet delivery delay versus time in Seconds.

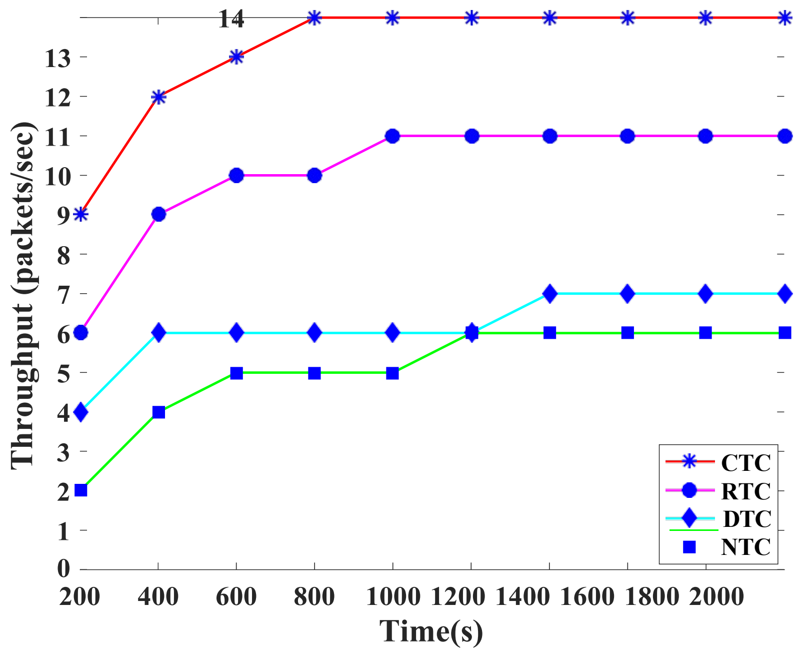


Figure 8. Throughput versus time in seconds.

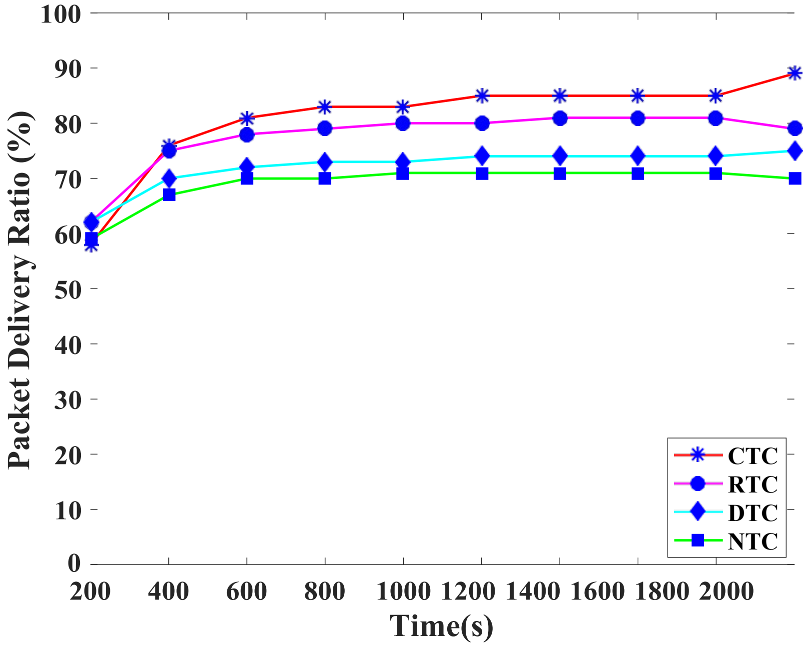


Figure 9. Packet delivery ratio versus time in seconds.

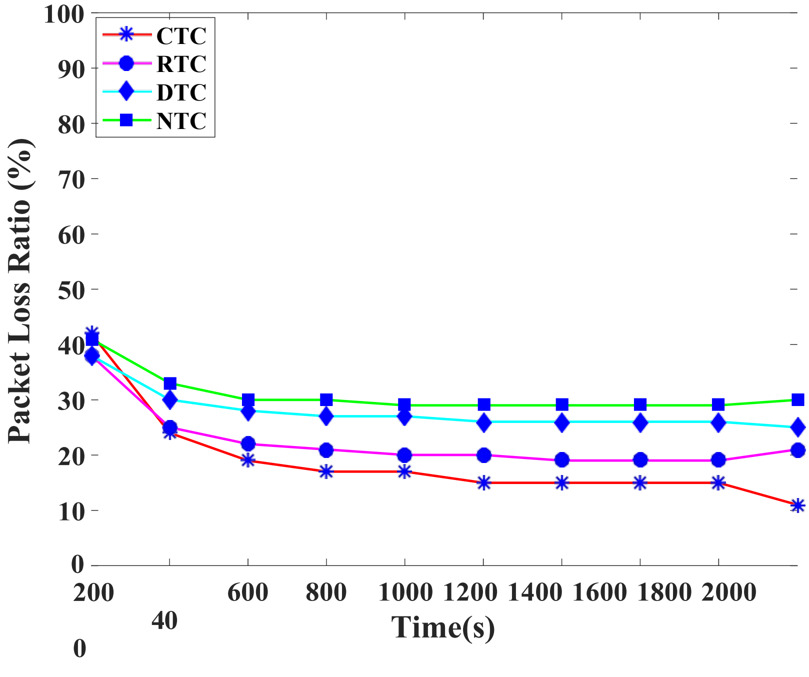
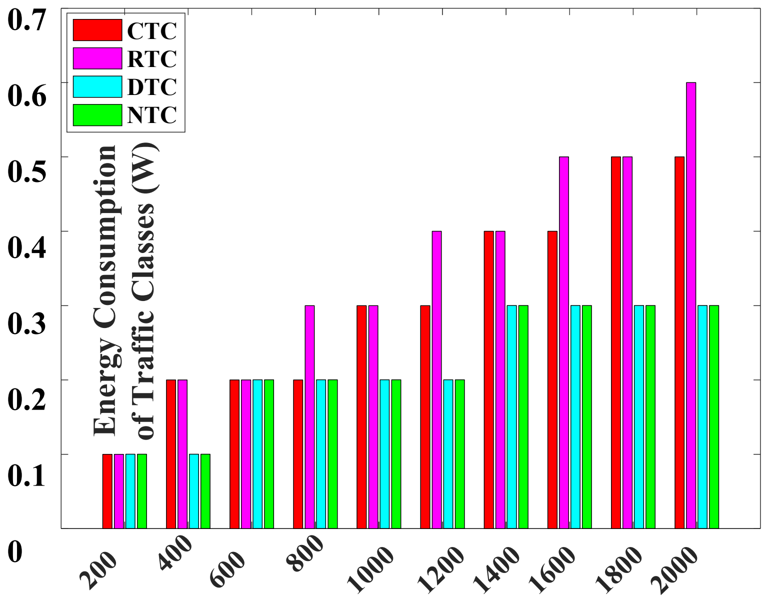


Figure 10. Packet loss ratio versus time in seconds.



Time(s)

Figure 11. Energy consumption of traffic classes versus time in seconds.

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