CONCERT INVESTIGATES AND IMPROVEMENTS END-TO-END COMMUNICATION DELAY ANALYSIS IN WIRELESS NETWORKS

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ABSTRACT:

Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) based wireless networks are becoming increasingly ubiquitous. With the aim of supporting rich multimedia applications such as high-definition television (HDTV, 20Mbps) and DVD (9.8Mbps), one of the technology trends is towards increasingly higher bandwidth. Some recent IEEE 802.11n proposals seek to provide PHY rates of up to 600 Mbps. In addition to increasing bandwidth, there is also strong interest in extending the coverage of CSMA/CA based wireless networks. One solution is to relay traffic via multiple intermediate stations if the sender and the receiver are far apart. The so called "mesh" networks based on this relay-based approach, if properly dned, may feature both "high speed" and "largesige coverage" at the same time. This thesis focuses on MAC layer performance enhancements in CSMA/CA based networks in this context. Firstly, we observe that higher PHY rates do not necessarily translate into corresponding increases in MAC layer throughput due to the overhead of the CSMA/CA based MAC/PHY layers. To mitigate the overhead, we propose a novel MAC scheme whereby transported information is partially acknowledged and retransmitted. Theoretical analysis and extensive simulations show that the proposed MAC approach can achieve high efficiency (low MAC overhead) for a wide range of channel variations and realistic traffic types Secondly; we investigate the close interaction between the MAC layer and the buffer above it to improve performance for real world traffic such as TCP. Surprisingly, the issue of

buffer sizing in 802.11 wireless networks has received little attention in the literature yet it poses fundamentally new challenges compared to buffer sizing in wired networks. We propose a new adaptive buffer sizing approach for 802.11e WLANs that maintains a high level of link utilization, while minimizing queuing delay.

INTRODUCTION:

In a computer or telecommunication network where participants communicate via a common physical medium, how we should coordinate their actions so that certain performance goals can be met? In the literature, this is known as the multiple access problem, with the corresponding protocols and mechanisms known as medium access control (MAC). The multiple access problem arises when the underlying medium is broadcast in nature, where messages from a station can be heard by all other stations that are in the listening area. With current physical layer techniques, if more than one station starts a transmission at the same time, all the transmitted frames will be lost. MAC layer protocols are therefore required to coordinate transmissions by competing stations to allow for sharing the common medium. The coordination techniques can be classified into four subcategories: frequency division multiple access (FDMA), time division multiple access (TDMA), code division multiple access (CDMA) and carrier sense multiple access with collision avoidance (CSMA/CA). In this thesis, we consider how to improve performance for 802.11 family protocols which are based on CSMA/CA In recent years, wireless sensor networks (WSNs) have revolutionized the world of distributed systems and enabled many new applications. WSNs play more and more decisive roles in various aspects such as wide-range environmental surveillance, short-range health monitoring, inventory tracking, military locating, and so forth and almost touch upon all aspects of our life, especially after successful release of the IEEE 802.15.4 standard [1]. Besides energy efficiency requirements in WSNs that withdraw energy from batteries, other performance metrics such as service time, throughput, and so forth need to satisfy actual requirements of many real-time applications. In particular, it should take two or more hop communications into account when node transmission range is not enough to cover the entire network area for remote environmental monitoring of reserved areas which are important fields of wireless sensor networking techniques. For multihop WSNs, the performance behaviors such as throughput, service delay energy efficiency, and so forth can be sharply deteriorated by two main reasons: the one is the impact of the “hidden terminal problem,” and the other is the establishment and maintenance of multihop routings. In contention-based wireless sensor networks, a node is not guaranteed to hear the signals from other nodes. If signals being transmitted from node A to node C cannot be sensed by node B, node B thinks that the channel is clear. As a result, node B might transmit packages to node C at the current transmitting. These two overlapped signals result in the failure of node C to capture either of the signals transmitted by node A or node B. This is called the hidden terminal problem, and node A can be considered as the hidden terminal of node B based on receiver C [2]. The hidden terminal problems bring about a large number of simultaneous transmissions or collisions, which must be eliminated or mitigated for guaranteeing network behaviors in multihop WSNs. In this paper, a novel algorithm HTC is proposed to eliminate or mitigate the impact of the hidden terminal problems. In addition, packets should go through one or more relay nodes transmitted from the sender to the sink, and these relay nodes should be well chosen for the energy-constrained WSNs. Correct selection of the relay node plays an important role in performance behaviors, and this selection process is called the routing establishment. Packets transmitted through the same transmission path can exhaust the energy of the nodes in this path soon, and the communicating path should be altered adaptively according to the energy condition of the nodes. And also, new routings should be reestablished in the cases that any node is discarded when it exhausts its energy or a new node is joining into the communicating network. The routing establishment or maintenance can consume the overwhelming majority of energy in WSNs, even up to 80% [3]. In our energy-saving time-critical applications, a parallel access scheme is proposed to dispense with taking the routing overhead into account for multihop transmissions. Furthermore, the existing performance analyses of CSMA/CA schemes in multihop wireless networks focus on how to mitigate the impacts of the hidden terminals [4–7] rather than how to derive the exact multihop behaviors or derive the multihop performance through the simple character superposition of several hops [8]. In this work, we propose a novel analysis model for CSMA/CA scheme based on a hidden terminal avoiding scheme HTC to analyze and improve the performance of multihop

WSNs touching upon both avoiding the impacts of hidden terminals and acquiring the exact multihop behaviors, without taking the routing establishment or maintenance into account.

RELATED WORKS

Literature reviews presented here are threefold: (1) references related to the means used for avoiding the problem of hidden terminals for multihop WSNs, (2) references related to MAC schemes accompanied with routing for multihop WSNs, (3) references related to performance analyses of CSMA/CA schemes for multihop WSNs. Many solutions have been proposed to eliminate or reduce the impact of the hidden-node problem in wireless networks [9], which can be roughly categorized as: (1) busy tone schemes; (2) Request-To-Send/Clear-To-Send (RTS/CTS) schemes, (3) carrier-sense tuning schemes, (4) hidden overhearing scheme, (5) node grouping schemes, (6) cross-layer schemes. Busy-tone multiple access method (BTMA) is proposed to evaluate and eliminate the hidden terminal problem in 1-persistent, non-persistent, and p-persistent CSMA schemes for the first time in [2], which introduces much control overhead for such a BTMA scheme. The handshake control message RTS/CTS is proposed to reserve the channel for a pair of a sender and a receiver, which can mitigate the impact of the hidden terminal problems greatly. The idea of RTS/CTS handshake is the widespread use of improving the performance of wireless networks for its simplification and efficiency such as [7, 10], and yet it is not an efficient solution for hidden terminal problems in wireless sensor networks [9]. A spatial-temporal analysis is presented in [7] to derive the real-world impact in multihop saturated and unsaturated throughput and then RTS/CTS is adopted to avoid the hidden terminal problems, in which the average number of hidden terminals is derived based on the distance between the sender and the receiver. RTS validation scheme is introduced in [10] to resolve the multihop false blocking process in which neighbors withdraw their transmissions for an entire DATA period without inquiring whether this DATA transmission is actually taking place, which can mitigate the multihop false blocking largely, but twice control messages can consume much energy in case of the relative small packet capacity. Two distributed adaptive power control algorithms which are adopted to minimize mutual interferences among links are proposed to avoid hidden terminals in [11]. Hidden overhearing is adopted in CR-MAC

[12] which exchanges channel-reservation information to mitigate the impacts of hidden terminal problems and which achieves much higher throughput than RTS/CTS mode under saturated traffic. Grouping strategy [13] is a simple and efficient method to solve the IEEE 802.15.4 hidden terminals, which groups nodes according to their hidden terminal relationship and separates the transmission period into several nonoverlapping subperiods one for a group. H-NAME scheme, a node-initiated grouping strategy, is proposed to solve the hidden terminals in [9], which is the improved strategy of [13]. A cross-layer detection and allocation (CL-DNA) scheme is proposed to solve the hidden terminal problems in IEEE 802.15.4 without the cost of extra control overhead in [14], which detects relationships of hidden nodes based on the overlapped signals and then allocates the hidden nodes into distinct sub-periods for transmissions. In multihop wireless sensor networks, performance analyses and improvements cannot be achieved only depending on one layer schemes such as the hidden terminal avoiding strategies related above. Cross-layer designs combining MAC with routing play an important role in performance analyses and improvements of multihop networks for IEEE 802.15.4 standards, such as [15–19]. Delay Guaranteed Routing and MAC (DGRAM) protocol is proposed to reduce latency for delay-sensitive WSNs in [15], whose routes of data packets are integrated into DGRAM without considering a separate routing protocol based on slot reuse for using TDMA-based MAC. An adaptive and cross-layer framework is proposed for reliable and energy-efficient data collection in WSNs in [16], which involves an energy-aware adaptation module that captures the application's reliability requirements and autonomously configures the MAC layer based on the network topology and the traffic conditions in order to minimize the power consumption for both single-hop and multihop networking scenarios. Hybrid protocol combining contention-based and TDMA-based MAC with an embedded cross-layer optimization solution to provide routing-layer coarse-grained QoS support for latency-sensitive traffic is proposed in [17], in which a novel channel-reservation technique is proposed to significantly reduce delay by allowing packets to go through multiple hops within a single MAC frame and by also giving them higher priority channel access to reduce possible queuing delay. A transient analysis is proposed to obtain the delivery delay distribution which combines unslotted MAC with routing protocol in [18],

whose nodes deploy to provide *k*-coverage for real-time applications. C-MAC, an optimized MAC layer based on CSMA/CA scheme for a topology of traffic destining to sink, is proposed in [19] to improve throughput for giving a larger priority to the *k*-tree core nodes which refer to the shortest paths to the sink containing exact *k*-leaves and coordinating among them to avoid collisions. Cross-layer designs are also adopted to evaluate and improve the performance of IEEE 802.11 networks, such as [20–22]. Interference level and the degree of spatial reuse of a frequency band can be controlled by varying the combination of the physical carrier-sensing (CS) range of the transmitter node and the target signal-to-interference ratio (SIR) set by the receiver node in [20], which improves throughput performance by the tradeoff between the CS range and SIR. Fairness for CSMA/CA scheme is derived by adopting only local information and performing localized operations without relying on overhearing in [21], which combines several novel rate control mechanisms including synchronized multiplicative decrease, proportional increase, and background transmission. A global optimality is derived through taking together individual optimality derived by local information for which different layers carry out distributed computation on different subsets of the decision variables in [22], which integrates three functions, congestion control, routing, and scheduling, in transport, network, and link layer into a coherent framework. Packet transmission process using CSMA/CA scheme regardless of IEEE 802.11 or IEEE 802.15.4 can be modeled as Markov process, and most performance analyses adopt this model. The relatively early and comprehensive analysis of CSMA/CA scheme using Markov chain is presented in [23]. Other similar analyses for CSMA/CA scheme with single-hop WSNs use Markov model such as [24–27]. Two assumptions different from usual ones, which refers to the sensing of the channel probability differently from the backoff stages and the obtaining the channel probability depending on the node numbers, are proposed to improve delay and throughput and collision probability, respectively, in [28]. Similar Markov chains for performance analyses of multihop networks are presented in [29–33]. Node is assumed according to two-dimensional Poisson distribution and packet collision probability depends on the distance between the source and the destination in [29] whose two Markov chains are used for the throughput analysis, but it takes the transmission probability as the same value regardless of hops. Multihop transmission adopts master-slave manner in [30] in which GTS slots of bridge modes are allocated by the sink. Simple character superposition of several hops is presented in [31] based on assumption that arrival process at the relay is linear combination of the output processes of the source nodes, in which one Markov chain for the node CSMA/CA scheme and one Markov chain for the physical channel transition are used to analyze multihop throughput and delay. Collision domain for each node is determined based on both the interference range and routing, and the optimal flow over a given set of routes for any number of classes is derived by a flow-deviation algorithm but its Markov chain is not based on CSMA/CA scheme in [32]. A linear feedback model is introduced to evaluate characters of CSMA/CA under a general assumption about the traffic for the first time in [33]. In this work, we propose analysis models to analyze and improve the performance of CSMA/CA scheme for multihop WSNs, accompanied with a novel HTC algorithm to eliminate or mitigate the impact of the hidden terminal problem and a parallel access scheme to dispense with taking the routing overhead into account. Routing establishment and maintenance consume much energy, which is analyzed elaborately in [34, 35]. At first, the HTC algorithm is presented, in which a transmitter in 2-hop circle can randomly choose a receiver in its transmission range just the nodes in 1-hop to establish HTC pair. A parallel access scheme is proposed, in which nodes regardless of hops are bestowed on the fair chance to transmit packets to its neighbor of close upper hop circle adopting CSMA/CA scheme, until packets to sink. Then, the comprehensive models adopting *n* semi-Markov chains to describe the behaviors of CSMA/CA scheme for the nodes in *n* hops contending to the channel and one macro-Markov chain to describe the channel behaviors are proposed to analyze and improve the performance of multihop IEEE 802.15.4 CSMA/CA scheme. *n* denotes the number of hops which refers to the ratio of the distance from a source to the sink to the transmission range which can be denoted by n=⌈d/R⌉n=⌈d/R⌉, *d* is the distance from a transmitter to the sink, and *R* is the transmission range. And then, the accurate statistical performance metrics of throughput and delay of unsaturated, unacknowledged IEEE 802.15.4 beacon enabled networks for 1-hop and 2-hop scenarios are predicted based on these models and improved strategies, in which nodes are assumed to locate randomly uniformly over a circle plane according to Poisson distribution with a density of λ. Moreover, comprehensive NS-2 simulations demonstrate that the analysis results of these models match well with the simulation results, especially for larger transmission range, and relative higher node density which is refers to large-scale multihop WSNs [35]. Besides, performance comparisons between our scheme (which can simply be denoted HTC scheme) and other multihop HTC-like schemes are also proposed based on the network parameters of node density λ, transmission range *R*, and traffic rate γ. Analysis and simulation results show that the delay behavior of HTC scheme is obviously improved compared to other schemes, while the throughput performance is improved in some cases of more node density and larger transmission range. We can consequently extend our models to analyze 3-hop or even higher hop networks. An important character of HTC scheme is that the multihop traffic has nonpreemptive priority over each other, meaning that the traffic regardless of hops has no priority over each other and with fair opportunity to be transmitted to receivers of its upper hop rather than its peers in the same hop. And the other character is that a HTC algorithm and a parallel access scheme are adopted in the CSMA/CA scheme analyses of multihop WSNs to improve the system behaviors. To our best knowledge, this is the first analysis of the IEEE 802.15.4 CSMA/CA unsaturated scheme which touches on both how to avoid the impacts of hidden terminal problems accompanied with bringing down energy consumption of the routing establishment or maintenance and how to derive the exact multihop behaviors. The main contributions in this paper are threefold. Firstly, a novel algorithm HTC is proposed to eliminate or mitigate the impacts of the hidden terminal problems, and a parallel access scheme to dispense with taking the routing overhead into account. Secondly, comprehensive and accurate models adopting Markov chains, combing the HTC algorithm and the parallel access scheme, are presented to analyze and improve the performance behaviors of time-critical large-scale multihop WSNs. Finally, comprehensive performance comparisons between HTC scheme and other hidden terminal avoiding schemes are proposed to validate the superiority of this time-critical scheme HTC based on the network parameters of node density, transmission range and traffic rate.

HTC ALGORITHM:

As references the universal method to mitigate the effects of hidden terminal problems for WSNs and WLANs is the RTC/CTS handshake scheme. RTS/CTS-based methods are particularly suitable for the IEEE 802.11 networks but unsuitable for the modified CSMA/CA scheme in IEEE 802.15.4 standard for several reasons. First, data frame length is nearly identical to that of RTS/CTS frames, which leads to the same collision cost. In addition, RTS/CTS message exchanges are energy consuming for both sender and receiver. RTS/CTS is only limited to use in unicast transmissions but not in broadcast. Moreover, extra throughput degradation is introduced to WSNs according to the exposed terminal problems. And also, the relative simple and effective method to mitigate the effects of hidden terminal problems for wireless sensor networks is the grouping strategy presented in [9, 13]. Grouping algorithm has several limitations used for large-scale sensor networks. First, the maximal number of groups in WLAN is six, which is not enough for so many pending grouping sensor nodes in large-scale networks. Second, grouping establishment or maintenance consumes much more energy in large-scale sensor networks for more handshake information exchanges are needed [9, 13, 35]. Third, grouping algorithm is developed for the case of one-hop networks and consumes much energy in the case of multihop networks. Finally, nodes should participate in a special group no matter whether they have frames to transmit or not, which consumes unnecessary energy if they have no frames to be transmitted. This passive grouping algorithm is not suitable for the large-scale sensor networks. For the large-scale multihop senor networks, the handshake information exchanges among sensor nodes can be sharply toned down through the establishment of Hidden Terminal Couple (HTC) between only two nodes. Moreover, nodes can only couple their hidden terminals when they have frames to be transmitted. This active HTC algorithm can consume much less energy for so many sensor nodes in large-scale networks. In our large-scale multihop senor networks, nodes can eliminate or mitigate their hidden terminal effects by establishing and maintaining their Hidden Terminal Couple (HTC) pairs

Step 1: HTC Pair Request

After the network initialization completing, each node can be aware which hop is belong to knows its hop circle. Also, all nodes in the network can establish their one-hop neighbor list (NL) and update this NL every run stage. As the HTC request phase starts up, a transmitter T in 2-hop circle (R<d<2RR<d<2R) can randomly choose a receiver R in its transmission range just in 1-hop circle, and then node T will send a HTC pair request frame, Couple request, to node R. That is to say, node T desires to establish the HTC coupled pairs with node R. This request message contains its one-hop neighbor information of node T. Node T contends the channel for this request with this request message, Couple request, following the CSMA/CA scheme. If node T is within one-hop circle (d<Rd<R), the coupled hidden terminal of node T is the sink, and node T transmits its *Couple.request* frame to the sink and establishes the HTC with the sink directly.

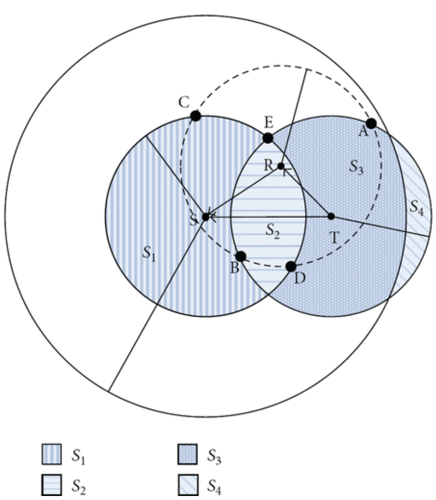


Figure 1 The establishment of HTC algorithm.

Step 2: HTC Information Exchange

After the Couple request message sent from node T is correctly received by node R, node R can acquire and fuse the one-hop neighbor information of node R and node T. At the end of this fusion, node R can also derive the hidden terminals between node R and node T. Then, an acknowledgement (ACK) message is broadcast by node R. This ACK message contains the information of one-hop neighbors of R and T, following the information of hidden terminals between node R and node T. After the ACK frame is correctly received by node T, node T can start up its data fusion process. At the end of this fusion, node T can also acquire the one-hop neighbor information of node R and node T, following the hidden terminals of node R and node T. The nodes within the one-hop circle of node R but not within the one-hop circle of node T are the hidden terminals of node T when node T transmits frames to node R, and the nodes within the one-hop circle of node T but not within the one-hop circle of node R are the hidden terminals of node R. Therefore, the nodes which are encircled by the pitch arc surrounded by, four points

A, C, B, and E (i.e., ACBEAˆACBEA^) that are the hidden terminals of node T. The nodes which cover the one-hop neighbors of node T except for the ones in the common area of one-hop circle between node T and node R are the hidden terminals of node R. The nodes which cover both the one-hop neighbors of node T and node R except for the ones in the common circle are the hidden terminals of HTL pair of node T and node R. Whenever node T transmits frames to node R, the hidden terminals of node T can shut off the transceivers to avoid the collisions.

After this HTC information exchange, node T and node R know the hidden terminals of each other. That is to say, the HTC coupled pairs are preliminarily established between node T and node R. Node T can choose the relay node R randomly, and the hidden terminals of node T and other relay nodes are also obtained through a similar way.

Step 3: HTC Information Notification

The relay node R can send the fused HTC message couple notify to the sink after the HTC information is exchanged. The message couple notify contains the hidden terminal information of the coupled pair of node T and node R. Node R notifies the sink that it establishes the HTC coupled pairs with node T, and the hidden terminals shut off their transceivers when node T transmits its packages to node R. After the HTC information is received by the sink correctly, the sink can update its HTC list, which contains the hidden terminal information of all HTC coupled pairs.

Also, the sink will exchange its one-hop neighbors with node R, and the nodes within the one-hop circle of the sink except for the common nodes of the circle centered R and the circle centered the sink are the hidden terminals of node R. These hidden terminals should shut off their transceivers when node R transmits frames to the sink. The sink is assumed to be the central node that manages all the HTC lists, and the sink fuses this hidden terminal information with the received HTC coupled information of node R and node T and establishes the HTC converge cast link list. The sink updates this link list after each transmission link buildup, such as the convergecast link of the transmission from node T and node R to the sink. If the node T is in the one-hop (d<Rd<R), the sink and node T are coupled each other, and the HTC list in the sink also can be regarded as the HTC convergecast link list which is actually the HTC list. In this step, the sink stores two lists which refer to the HTC list and HTC convergecast link list and updates these two lists after each transmission link build up.

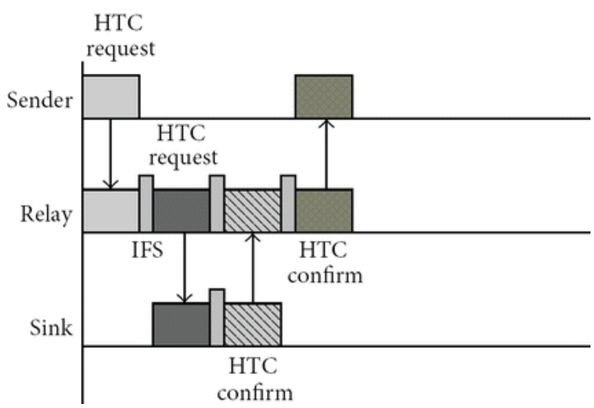


Figure 2 Sequence chart of the establishment of HTC algorithm.

Step 4: HTC Information Confirmation

After the HTC list and the HTC convergecast link list are established, the hidden terminals of the sink when node R transmits messages to the sink and the hidden terminals of node T when node T transmits messages to node R shut off their transceivers. The sink can send a message couple confirm to node R to confirm this couple process, which contains the hidden terminal information of node R when it transmits its relayed packages to the sink and the hidden terminal information of node T when node T transmits its packages to node R. After node R receives this couple confirm message correctly, node R can send the message couple confirm to node T to confirm this HTC couple process. The HTC couple establishment is finished with node T receiving this couple confirm message correctly. Collisions can be avoided or mitigated since the hidden terminals of node T in the 2-hop circle can shut off their transceivers when node T chooses a random node R in upper hop to transmit packages. All nodes can carry out the HTC couple scheme in similar way when they have pending packages to transmit. Nodes receiving the frame can trigger the HTC of the transmission nodes and the corresponding received nodes. This active HTC algorithm can consume much less energy and can avoid or mitigate the effects of hidden terminals effectually. The sequence chart of the HTC scheme is demonstrated as Figure 2. Transmitter T in 2-hop circle can

ISSN NO:2236-6124

randomly choose a receiver R (relay node) in its transmission range just the node in 1-hop and send a message couple request to node R. Node T and node R can exchange their one hop neighbors, and then the hidden terminals of each one can be derived. The HTC pair of node T and node R can be established. Node R sends this HTC establishment message couple notify containing their hidden terminals to the sink. Sink fuses this HTC information accompanying the hidden terminal information of node R and then transmits a message couple confirm to node R. Node R sends this couple confirm to node T to confirm the HTC of node R and node T.

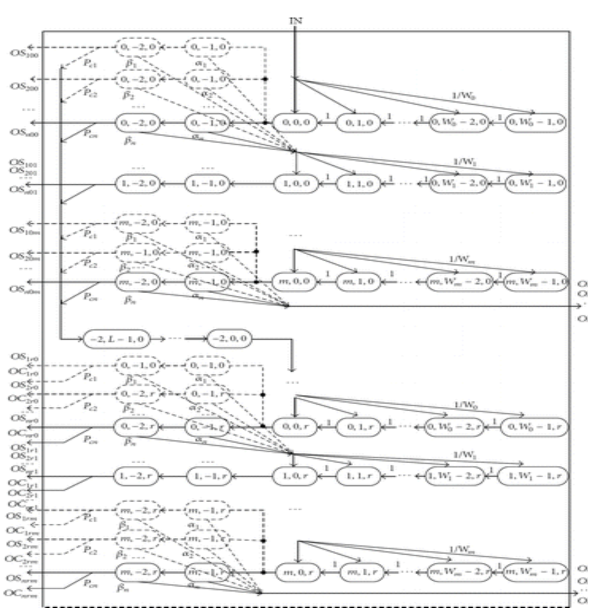
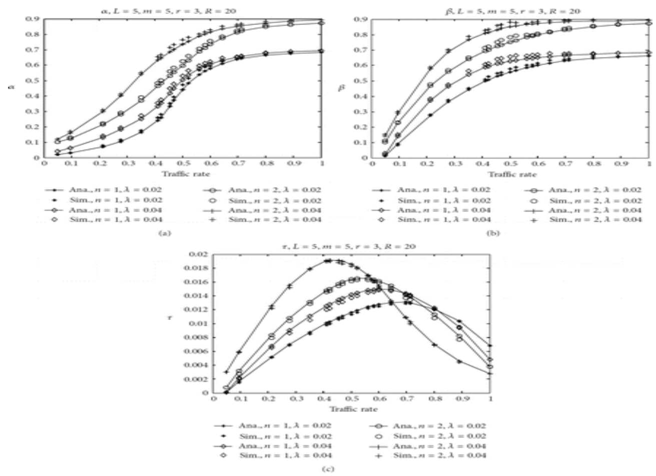
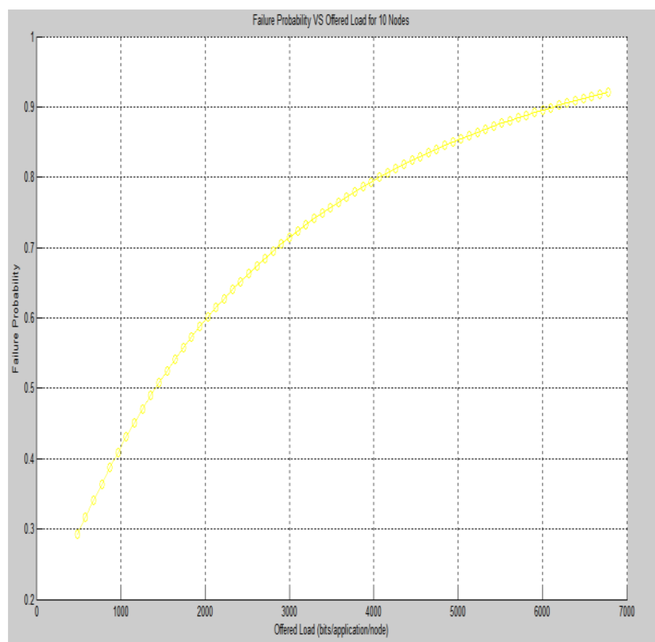


Figure 3 Markov chain model for slotted IEEE 802.15.4 CSMA/CA scheme

SIMULATION RESULT:





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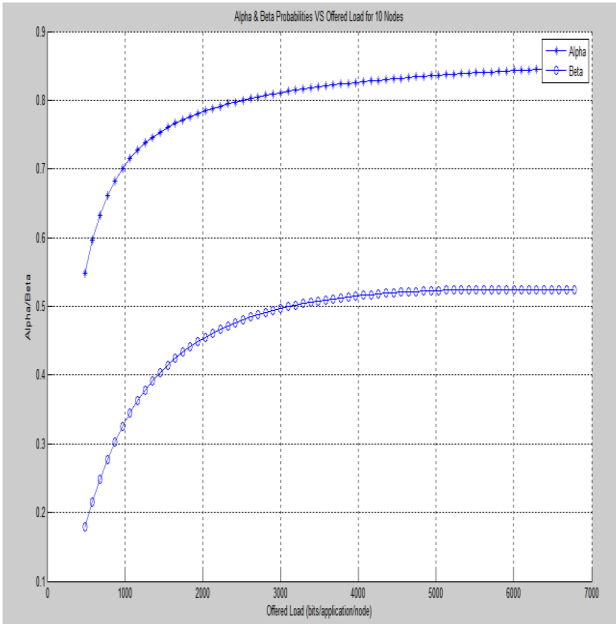

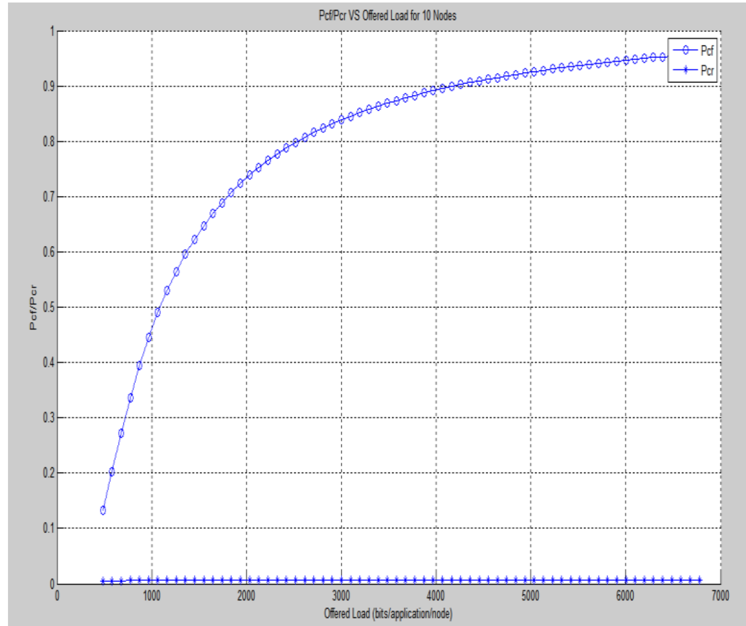

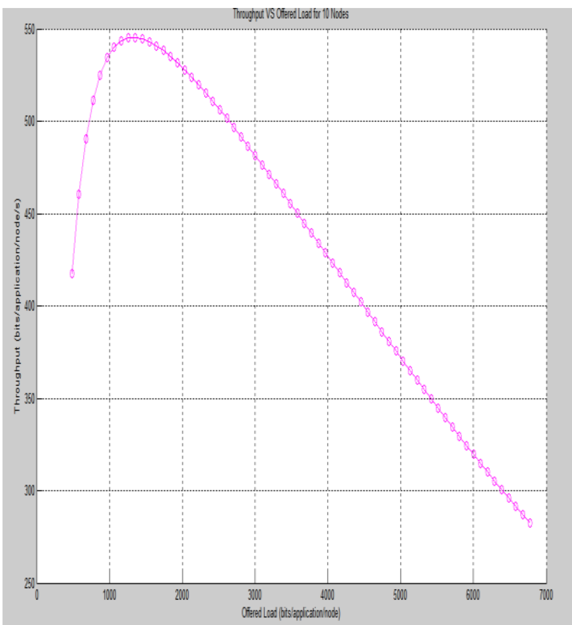

CONCLUSION:

In this paper, we have presented a slotted CSMA/CA scheme HTC scheme, for multihop IEEE 802.15.4 networks using accurate and comprehensive *n* semi-Markov models and one macro-Markov model. At first, two strategies are performed to improve the performance of multihop WSNs: the HTC algorithm and a parallel access scheme. Then, the comprehensive models adopting *n* semi-Markov chains to describe the behaviors of CSMA/CA scheme for the nodes in *n* hops contending to the channel and one macro-Markov chain to describe the channel behaviors are proposed to analyze and improve the performance of multihop IEEE 802.15.4 CSMA/CA scheme. And then, the accurate statistical performance metrics of throughput and delay of unsaturated, unacknowledged IEEE 802.15.4 beacon enabled networks for 1-hop and 2-hop scenarios are predicted based on these models and improved strategies, in which nodes are assumed to locate randomly uniformly over a circle plane according to Poisson distribution with a density of λ. We consequently extend our models to analyze 3-hop or even higher hop networks

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