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New Algorithm for High Throughput of IEEE 802.11 Distributed Coordination Function

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The Backoff mechanism is a basic part of a Media Access Control (MAC) protocol which provides addressing and channel access control mechanisms that make it possible for several terminals or network nodes to communicate within a multi-point network. Since only one transmitting node uses the channel at any given time, the MAC protocol must suspend other nodes while the media is busy. In order to decide the length of node suspension, a backoff mechanism is installed in the MAC protocol. The choice of backoff mechanism should consider generating backoff timers time, which is uniformly selected from the Contention Window (CW) and allow adequate time for current transmissions to finish and, at the same time, avoid unneeded idle time that leads to redundant delay in the network. Moreover, the backoff mechanism used should decide the suitable action to be taken in case of repeated failures of a node to attain the media. Further, the mechanism decides the action needed after a successful transmission since this action affects the next time backoff is needed [2]. Several back-off schemes will be discussed and a new proposed algorithm has been proposed to achieve high throughput of the IEEE 802.11 DCF.

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1. Introduction

In IEEE 802.11 wireless local area networks (WLANs), network nodes experiencing collisions on the shared channel. Access to this media is controlled by MAC protocol [1]. An ad hoc network typically refers to any set of networks where all devices have equal status on a network and are free to associate with any other ad hoc network devices in link range. Traditionally, ad hoc network refers to a mode of operation of IEEE 802.11 wireless networks [2-3]. This is particularly true within the past decade, which has seen wireless networks being adapted to enable mobility. There are currently two variations of mobile wireless networks, infrastructure and ad hoc wireless networks. Wireless networking increases availability and allows rapid deployment of wireless transceivers in a wide range of computing devices such as PDAs, laptops and desktop computers. Wireless networks came as a result of the technological advances and extensions of LAN model as detailed in the IEEE 802.11 standard. The IEEE 802.11 WLAN MAC/PHY specification is one of the recommended international standards for WLANs [1]. The standard contains technical details for the Medium Access Control layer (MAC) and the Physical layer (PHY) of the communication protocol.

The Distributed Coordination Function (DCF) is the fundamental MAC technique of the IEEE 802.11 based WLAN standard. DCF employs a CSMA/CA with Binary exponential backoff algorithm [4]. DCF requires a station wishing to transmit to listen for the channel status for a DIFS interval. If the medium is continuously idle for DCF Interframe Space (DIFS) duration, only then it is supposed to transmit a frame. If the channel is found busy during the DIFS interval, the station should postpone its transmission [5]. In any network where a number of stations contend for the wireless medium and if there are multiple stations sense the channel busy and defer their access, they will also virtually simultaneously find that the channel is released and then try to seize the channel. As a result, collisions may occur. In order to avoid such collisions, DCF also specifies random backoff, which forces a station to defer its access to the channel for an extra period [5]. The length of the backoff period is determined by the following Eq. [6]:

*Backoff Time=(Random () MOD CW)*Slot Time* (1)

where CW is the current contention window size and it is chosen in the range [0, CW-1]. A simple algorithm of CSMA/CA is shown in Fig. (1) [7].

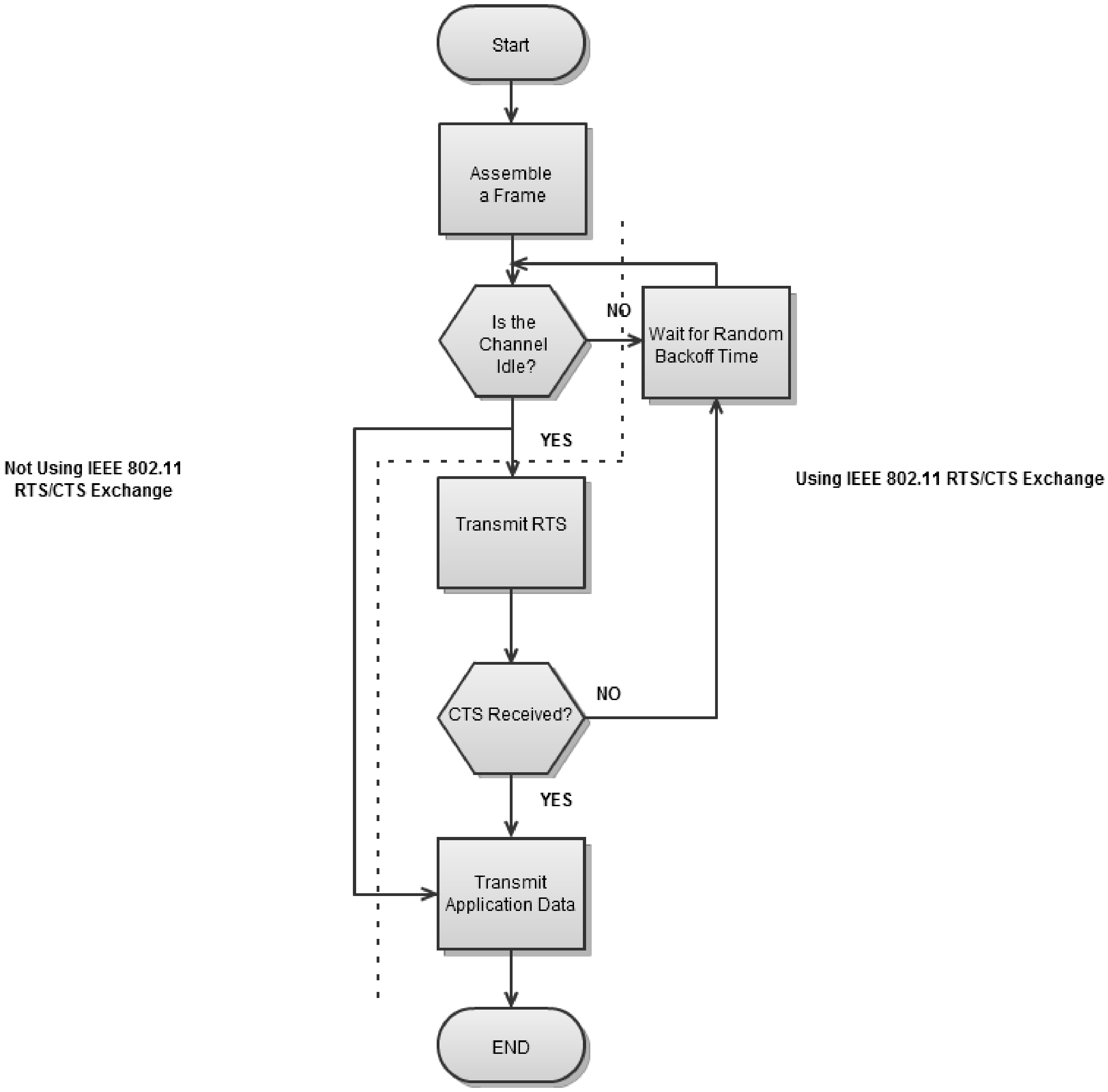

Fig. (1) A Simple CSMA/CA algorithm

DCF also has an optional virtual carrier sense mechanism that exchanges short Request-to-send (RTS) and Clear-to-send (CTS) frames between source and destination stations during the intervals between the data frame transmissions [5]. Packet collisions are not completely eliminated in the IEEE 802.11 MAC/PHY standard due to the distributed nature of the competing nodes and the bursty traffic arrival at the nodes. In the IEEE 802.11 DCF scheme, the senders of the colliding packets need to refrain from immediate retransmissions in order to avoid repeated collisions. Thus, each competing node sets up a backoff timer according to a randomly selected backoff time period and enters the backoff state. This backoff time period is selected uniformly between 0 and the Contention Window (CW) [1,8].

2. Research motivation

The Binary Exponential Backoff algorithm (BEB) and some other proposed algorithms suffer from the following shortcoming:

a. Fairness: BEB tends to have a preference for most recent contention winner and new contending nodes over other nodes when allocating channel access. Determining backoff period is accomplished by choosing a random backoff value from a contention window (CW) which has smaller size for new contending nodes and contention winners. This behavior causes what is known as "Channel capture effect" in the network [9].

b. Power: main sources of power in mobile nodes are batteries. Taking into account that each node acts as a sender, a receiver and a router at the same time raises the possibility of breaking the connectivity of the network whenever the battery of one node is fully consumed [2].

c. Stability: BEB has been designed to be stable for large number of nodes. Studies showed that it is not [6,9-12].

d. Performance: the performance of the network measured by the total network throughput and the average packet delay [2,13].

Now, in order to overcome all above shortcomings, a new proposed backoff algorithm is presented in this work. Our proposed algorithm is composed of the good features from other backoff algorithms as we will be shown in next sections below.

3. Literature review

Many backoff algorithms are proposing modifications to BEB to increase performance and increase the utilization of network resources for the WLANs. A discussion for some of these algorithms will be taken.

3.1 Binary Exponential Backoff (BEB)

The BEB scheme is widely used in MAC layer protocols due to its simplicity. In this scheme, each node doubles its contention window, CW, up to the maximum contention window (CW_{max}) after a collision occurs and resets its CW to the minimum value (CW_{min}) after a successful transmission:

$$\begin{cases} CW \leftarrow \min\,(2 \cdot CW, CW_{max}) & \text{upon collision} \\ CW \leftarrow CW_{min} & \text{upon success} \end{cases} \qquad (2)$$

The values of the CW3s and CW_{max} are pre-determined based on the expected range of the number of active nodes and the traffic load of the network. As we have pointed out, the BEB scheme suffers from fairness issues under high traffic load and low throughput problems when network size is large [1,2,10,14,15]. Figure (2) shows the behavior of the BEB algorithm contention window with the iteration (number of successive failure) and in success case.

3.2 Multiplicative Increase Linear Decrease (MILD)

The MILD algorithm was introduced in the MACAW scheme. In the MILD scheme, a collided node increases its CW by multiplying it by 1.5. A successful node decreases its CW by one unit, where a unit is defined as the transmission time of the RTS packet. The MACAW protocol assumes that a successful node has a CW value that is related to the contention level of the local area.

The current CW is included in each transmitted packet and a contention window copy mechanism is implemented at each overhearing node to copy the CW of the overheard successful transmission into its local CW. The operation of the MILD scheme can be summarized as follows:

$$\begin{cases} CW \leftarrow \min\,(1.5 \cdot CW, CW_{max}) & \text{upon collision} \\ CW \leftarrow CW_{packet} & \text{upon overhearing success} \\ CW \leftarrow \max\,(CW - 1, CW_{min}) & \text{upon success} \end{cases} \qquad (3)$$

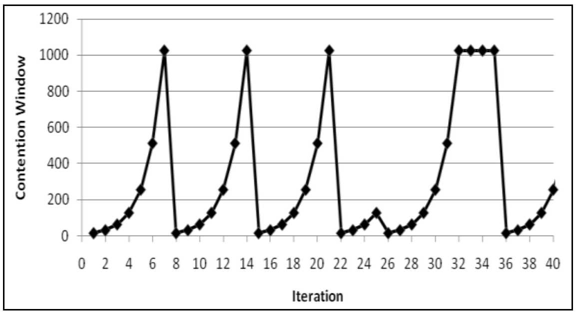

Fig. (2) BEB Algorithm

Where CW packet is the CW value included in the overheard (successful) packet. Besides increasing the header size of the RTS packets, the MILD scheme may also suffer from the migration of the CW value into areas with different contention levels that do not match the CW values. Figure (3) shows the behavior of the algorithm for all cases [1].

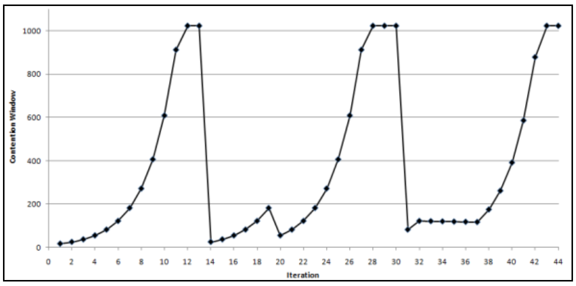

Fig. (3) MILD Algorithm Behavior

3.3 Linear Multiplicative Increase Linear Decrease (LMILD)

LMILD is another backoff algorithm for the IEEE 802.11 DCF scheme. The operation of the LMILD scheme is based on an additional piece of information available to network nodes in the IEEE 802.11 WLANs. This additional information is the knowledge of the packet collisions on the channel. In this algorithm, we can note that the network nodes are assumed not capable to perform collision detection while transmitting packets. According to the IEEE 802.11 MAC/PHY standard, every node is capable of physical carrier sensing. When a backoff or idle node senses the channel busy for a period of the RTS packet transmission time but the packet header is not detected and reported by the physical layer, it knows that an RTS packet collision has taken place. The senders of the colliding RTS packets will become aware of the collision when the CTS reply is not received before timeout occurs. In addition to this information, nodes will also overhear successful packet transmissions [1].

In the LMILD algorithm, each node experiencing an RTS collision increases its CW by multiplying it by the factor mc. Any node overhearing a collision with the help of the above-mentioned technique increases its CW by lc units (slots). When a successful RTS transmission takes place, all nodes (including the sender, the receiver, and all overhearing neighbors) decrease their CWs by ls units. Thus, the operation of the LMILD algorithm can be summarized as in Eq. (4) and the behavior as in Fig. (4) [1]:

$$\begin{cases} CW \leftarrow \min\left(m_c \cdot CW, CW_{max}\right) & \textit{upon collision} \\ CW \leftarrow \min\left(CW + l_c, CW_{max}\right) & \textit{upon overhearing collision} \\ CW \leftarrow \max\left(CW - l_s, CW_{\min}\right) & \textit{upon experiencing or} \\ & \textit{overhearing success} \end{cases} \quad (4)$$

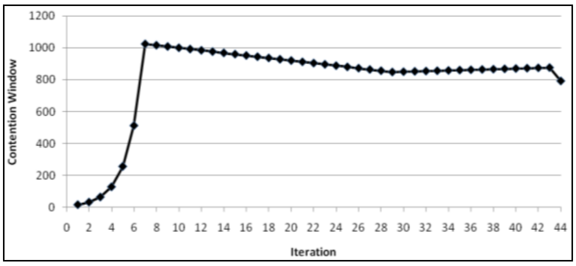

Fig. (4) LMILD Algorithm Behavior

3.4 Exponential Increase Exponential Decrease (EIED)

In EIED, the contention window size (CW) is exponentially increased by a backoff factor r_1>1 whenever a packet is involved in a collision, and is exponentially decreased by a backoff factor r_D>1 if a packet is transmitted successfully. EIED backoff algorithm can be expressed as follows:

$$\begin{cases} CW \leftarrow \min\left(r_1 \cdot CW, CW_{max}\right) & \textit{upon collision} \\ CW \leftarrow \max\left(CW/r_D, CW_{min}\right) & \textit{upon success} \end{cases} \quad (5)$$

where CW_{min} and CW_{max} are the minimum and the maximum contention window sizes, respectively. In general, the relationship between r_1 and r_D is given by:

$$r_1^m = r_D^n \quad (6)$$

where m and n are integers greater than or equal to 1 [16], Figure (5) shows the EIED behavior.

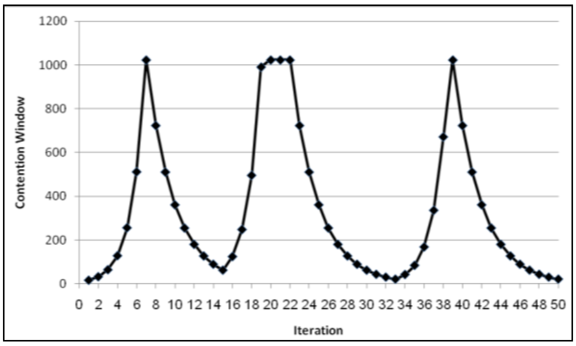

Fig. (5) EIED Algorithm Behavior

3.5 Fibonacci Increment Backoff (FIB)

Increasing the size of CW in case of failure to transmit tends to rapidly increase the size of CW to even larger sizes. Reaching such large window sizes decreases the expected wait time for a given node to access to the shared medium. Moreover, a large window size tends to contribute to increasing channel idle times, leading to a major waste in the shared channel bandwidth. Motivated by this above observation, authors of [9] propose a new backoff algorithm to improve performance. The well-known Fibonacci series is defined by the following formula:

$$fib\ n = fib\ n-1 + fib\ n-2,\ fib\ 0 = 0,\ fib\ 1 = 1,\ n \geq 0 \qquad (7)$$

This series has a number of interesting characteristics. Amongst these characteristics is a special value called the golden section property; the golden section property is obtained by calculating the ratio between every two successive terms in the Fibonacci series. After a certain number of terms, the ratio converges to a limit of $(1+52 \approx 1.618)$ in the FIB algorithm $fib(n)$ was used described in Eq. (7) as the new size of CW, leading to reducing the increment factor when more transmission failures take place and hence introducing smaller increment on large window sizes. The FIB algorithm could be expressed as in Eq. (8) and figure (6) shows the behavior [9]:

$$\begin{cases} CW \leftarrow Next_{FibonacciNumber} & \text{upon collision} \\ CW \leftarrow CW_{\min} & \text{upon success} \end{cases} \qquad (8)$$

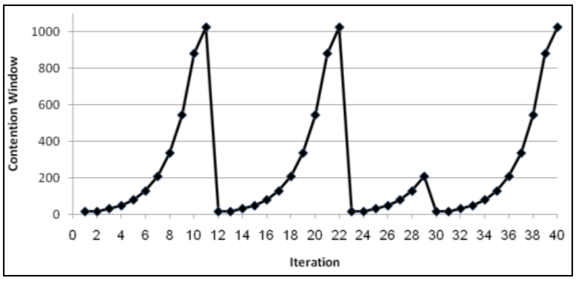

Fig. (6) FIB Algorithm Behavior

3.6 Pessimistic Linear Exponential Backoff (PLEB)

This algorithm assumes that a transmission failure is due to the presence of congestion in the network. This congestion could be the result of a high traffic load present in the network or a larger number of nodes located in a given network region [2]. PLEB works on the premise that congestion is not likely to be resolved in the near future.

Therefore, as a first response to a transmission failure, PLEB exponentially increases the contention window size. An exponential increment forces a longer waiting time before trying the next transmission. However, after a number of exponential increments, PLEB starts to increase the timer linearly instead in order to avoid increasing backoff more excessively. The basic functionality of PLEB aims to a less dramatic growth of the contention window size towards the maximum value allowing nodes to perform more attempts to access the channel after a reasonably affordable backoff time [2]. Figure (7) shows the behavior of the PLEB algorithm.

$$\begin{cases} CW \leftarrow 2 \cdot CW & \text{upon collision if iteration} < N \\ CW \leftarrow \min(CW + l,\ CW_{\max}) & \text{upon collision if iteation} > N \\ CW \leftarrow CW_{\min} & \text{upon success} \end{cases} \qquad (9)$$

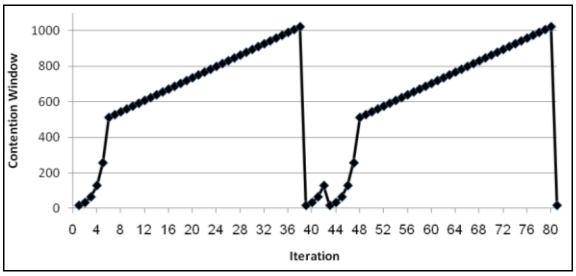

Fig. (7) PLEB Algorithm Behavior

1.1 Optimistic Linear Exponential Backoff (OLEB)

In order to overcome the problem of redundant backoff times, a new backoff algorithm that implements less dramatic increments for early backoff stages is proposed. For the first (N) transmission failures, the Optimistic Linear Exponential Backoff (OLEB) starts with a linear increment factor first before applying the exponential increment. The value of N has been chosen to allow more use of the linear behavior [2]. Figure (8) shows the algorithm behavior.

$$\begin{cases} CW \leftarrow CW + l & \text{upon collision if iteration} < N \\ CW \leftarrow \min(2.CW,\ CW_{\max}) & \text{upon collision if iteation} > N \\ CW \leftarrow CW_{\min} & \text{upon success} \end{cases} \qquad (10)$$

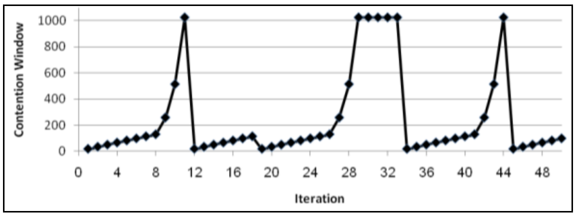

Fig. (8) OLEB Algorithm Behavior

2. Proposed algorithm

A new algorithm is proposed which discusses the node power and the node packet drop after reaching the maximum allowed contention window. The proposed algorithm mechanism is linearly increased at first N transmission failure and then exponentially increases in the second stage till M iteration it starts again with linear increments. The other part of the algorithm that manage the fairness when a success transmission occur, exponentially decrease has been proposed in success transmission case. Equation (11) illustrates the mechanism of the proposed algorithm and figure (9) shows the behavior of the algorithm.

3. Simulation results and analysis

The simulation has been taken for three algorithms which are BEB , LOG and the proposed algorithm with different number of nodes in each topology.

$$\begin{cases} CW \leftarrow CW + l & \text{upon collision if iteration} < N \\ CW \leftarrow 2 \cdot CW & \text{upon collision if iteration between } (N,M) \\ CW \leftarrow CW + l & \text{upon collision if iteration} > M \\ CW \leftarrow CW/2 & \text{upon success} \end{cases} \tag{11}$$

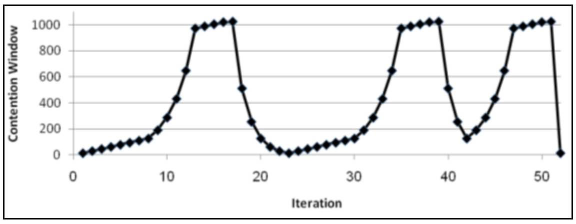

Fig. (9) Proposed Algorithm Behavior

As shown in the Fig. (10-12) the collision is reduced in the proposed algorithm also for large number of nodes.

4. Conclusion

In this paper a new backoff algorithm has been introduced and it is successfully reduces the number of collision that occurs in other algorithm which is also maximize the battery life time of the node (power consumed by the node due to minimum collision) and fairness of channel sharing. This algorithm does not need any changes in IEEE 802.11 MAC/PHY hardware. Only software or driver modifications are necessary to meet the algorithm mechanism.

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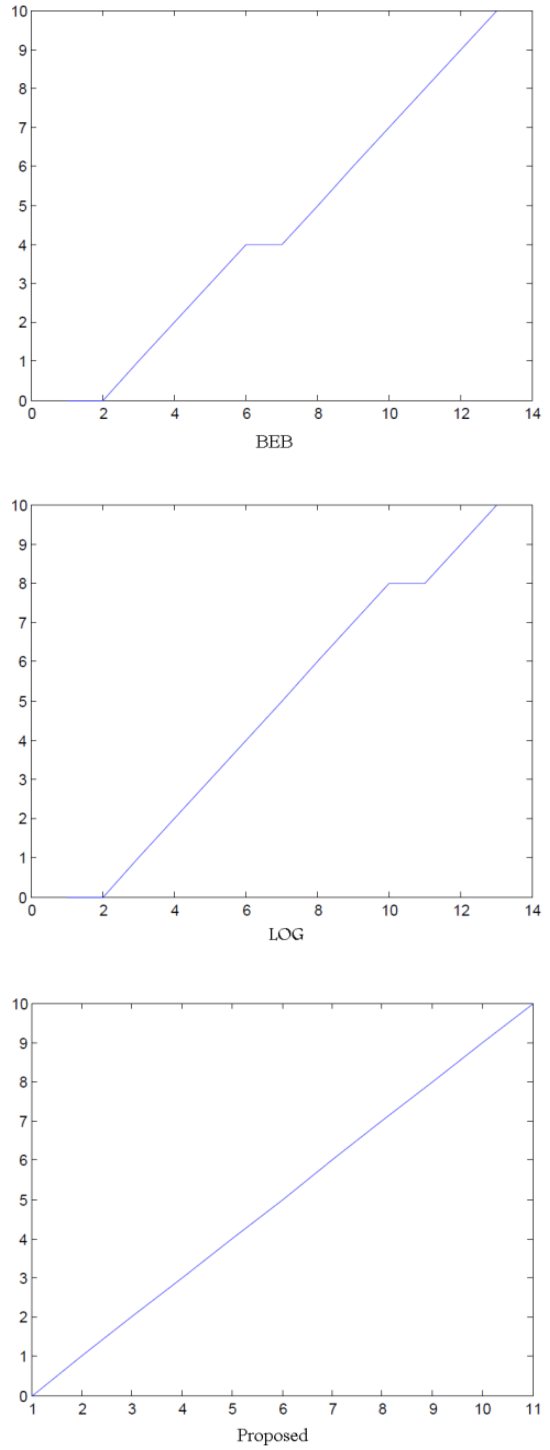

Fig. (10) Throughput for 10 Nodes

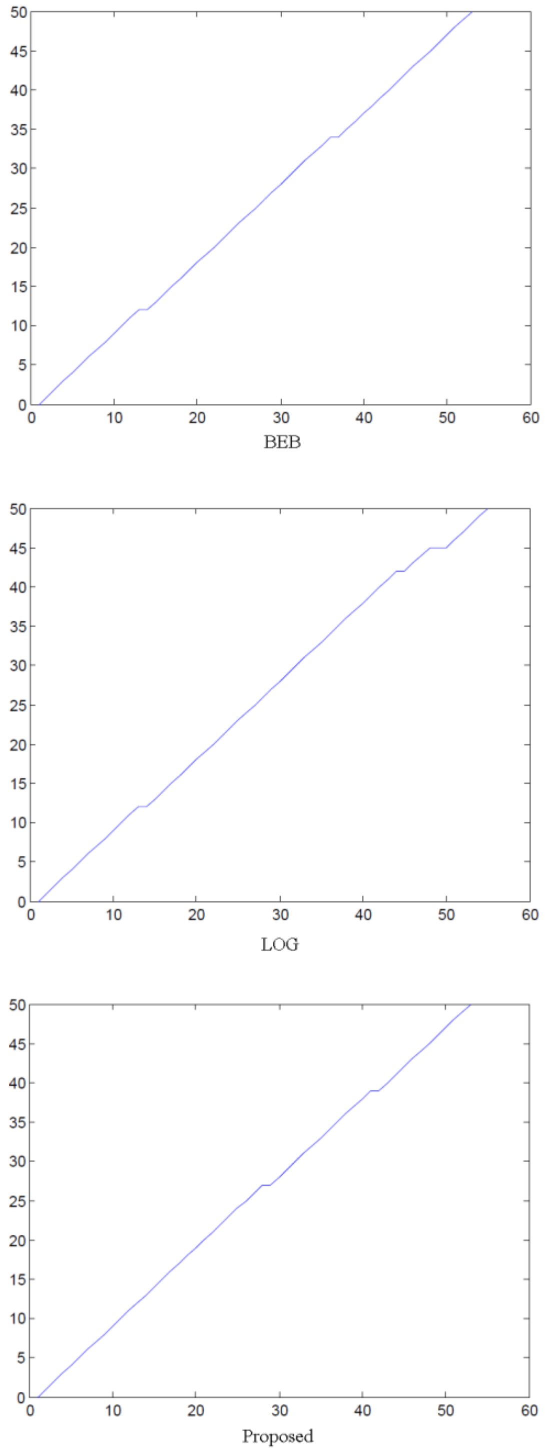

Fig. (11) Throughput for 50 Nodes

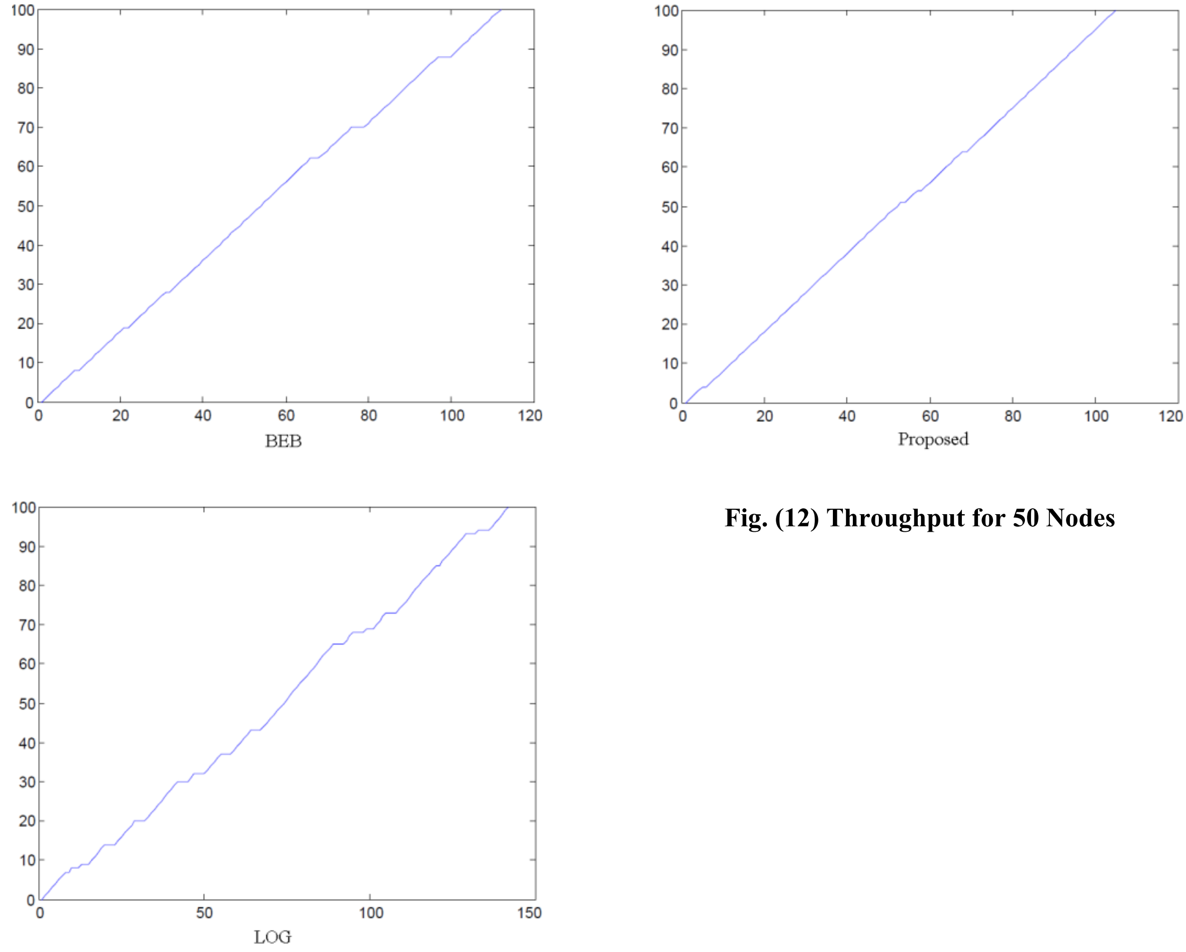

Fig. (12) Throughput for 50 Nodes