A New Method for Adaptive Broadcast Scheduling in Mobile Ad Hoc Networks

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Summary
A Mobile AdHoc network is a collection of interconnected computers, which had geographically separated through a large distance. The topology of the Mobile Ad Hoc network changes dynamically. The initial slot assignments may cause interferences among the nodes while transmitting. When the new link detects / removes, the initial slot assignment had computed again. Many heuristics methods are proposed to improve the channel efficiency. In this paper, we propose an adaptive distributed broadcast scheduling for spatial time division multiple accesses in mobile ad hoc networks that computes the slot assignments according to the changes in the topology. This new method obtains a Minimal frame length and finds the maximum node transmissions. Results show that this method improves the guaranteed throughput and outperforms an improvement over others.

Key words:
Carrier Sense Multiple Access, Time Division Multiple Access, Frequency Division Multiple Access, Code Division Multiple Access, New Adaptive Broadcast Scheduling.

1. Introduction

A Mobile Ad Hoc network is a collection of interconnected computers, which had geographically separated through a large distance. All the nodes share a common transmission medium. Two types of schedules exits for Mobile Ad Hoc networks namely Broadcast scheduling and link scheduling.

In broadcast scheduling, the transmission of a node has received by all the nodes within its transmission range. Because of this nature of broadcasting medium, the transmission of one node may be interfered with the transmission of the other nodes.

Two types of interferences namely primary and secondary interferences are possible in Mobile Ad Hoc network. Primary interferences occur when a node transmits and receives at the same time. Secondary interferences occur when a node unwittingly interferes with the transmission of the other nodes. In fig 2 the transceivers a and b are within the transmission range of each another. In this case, if a and b starts transmission to each other at the same time, then both the transceivers will be expected to transmit and receive simultaneously. We refer to this as type1 primary interference.

In Fig 1 the transceivers a and b are not within the transmission range of one another, but there is a third transceiver c which is within the transmission range of both a and b. In this case if a and b start simultaneous transmissions to each other then c will be expected to receive from both a and b at the same time. We refer to this as type2 primary interference.

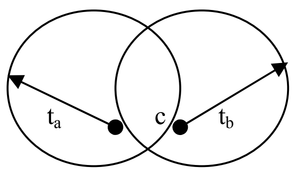

Fig. 1 Type 2 interferences

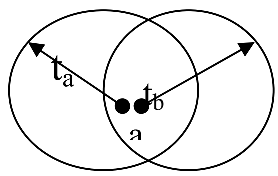

Fig. 2 Type 1 interferences

There are two classes of protocols for sharing the common medium: Static and Dynamic channel access classes. TDMA is a static channel access method where the transmission time was divided into fixed length slots. Two or more non-interfering nodes can reserve the same slot. However, the topology of the Mobile Ad Hoc networks changes dynamically.
A node joins/leaves the network. Hence, the initial slot assignments may produce interferences with the other node transmissions. There are two types of broadcast scheduling methods for Mobile Ad Hoc networks, namely centralized and distributed. In centralized broadcast scheduling methods, a central controlling node was

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maintained. This node collects the state information of the other nodes in the network and prepares an interference free schedule for all the nodes. This node runs the new schedule. However, the current transmission stops until the new schedule distributes to all the nodes. Hence, this is not suitable for the realistic environments.
In distributed broadcast scheduling, no such central computing node is maintained. Each of the nodes in the network builds its state information from its 1-hop, 2-hop neighbor's state information. A new node had to undergo the registration, resolution process and then distributes the new schedule to all the nodes in the network. Then in the next frame time, the new schedule implements. The joining node do not stop transmission of the existing nodes. Adaptive broadcast scheduling suits the heavily loaded dynamic Mobile Ad Hoc network very much.

In this paper, we propose a new adaptive broadcast scheduling method called NABS for transmission scheduling in Mobile Ad Hoc networks. The main aim of NABS is to obtain the Minimal frame length and the maximum node transmissions.

We also propose a simple method for adapting to the changes like joining/leaving the network. In [1], [2], [3],[10] adaptive broadcast scheduling is discussed where luyi's method[4] is used to compute the initial slot assignments. It is observed that NABS performs better than the method suggested in BSP [8]. One set of results are given in Table 1 and Table 2 for the example network in Fig 4. The Fig 6 and Fig 7 prove that NABS outperforms the existing methods discussed in [1]-[12].

The remainder of the paper has organized as follows.
Section 2 describes the distributed method for adaptive broadcast scheduling where the process of registration and resolution of a new node. Section 3 describes the NABS protocol. Section 4 analyzes the NABS protocol. Section 5 presents the results of the NABS protocol and compare them with the other existing methods. Section 6 presents the conclusions.

2. Distributed Method for Adaptive Broadcast Scheduling.

In adaptive broadcast scheduling, a central computing center is not maintained. Instead, each node maintains the state information record. Each node constructs this record by collecting information from its 1-hop, 2-hop neighbors.

The state information record INFO contains the following details

1. Node id.
2. List of 1-hop, 2-hop neighbors and their slots information (local State Information).
3. The list of nodes out of its neighbors' transmission range and their slots information are updated in a record called OUT.
4. The current frame size.
5. The current maximum slot number.
6. The degree of the network.
7. The max hops distance of the network.
8. The network connectivity.

2.1. Joining of the network.

Registration and Resolution are the two issues to consider when a node joins the network. Each slot time comprises identification interval and a payload interval. Each terminal decides whether to transmit an identification packet. A new node have to transmit an identification packet, otherwise it remains in receiving mode only. When a node receives an identification packet, it understands that it has a new neighbor.

The identification interval again consists of four mini-slots.

1. Broadcast mini-slot.
2. Request mini-slot.
3. Collision mini-slot.
4. Monitor mini-slot.

2.1.1. The Process for registration

The purpose of the registration process is to make the new node known to all its 1-hop, 2-hop neighbors. If two or more nodes at a hop distance of one or two are willing to join the network, then only one of them succeeds through the registration process. A node that succeeds the registration process is called a Monitor. A node reserves the Broadcast-mini slot, if none other than it is joining the network. If node B too wishes to join the registration process, it has to wait until A completes the registration process and become the monitor.

If a joining node A identifies an empty Broadcast – mini _ slot, it requests for registration by sending the Request_ control packet in Request- mini -slot. If A did not detect any collision when it was broadcasting its control packet and if it observes an empty Collision _ mini-slot, then A understands that none of its 1-hop, 2-hop neighbors is making a request for registration process.

Hence A reserves the Monitor-mini-slot by passing a monitor _ h control packet. If none other than A had claimed to become the Monitor, A becomes the Monitor and the registration process ends.

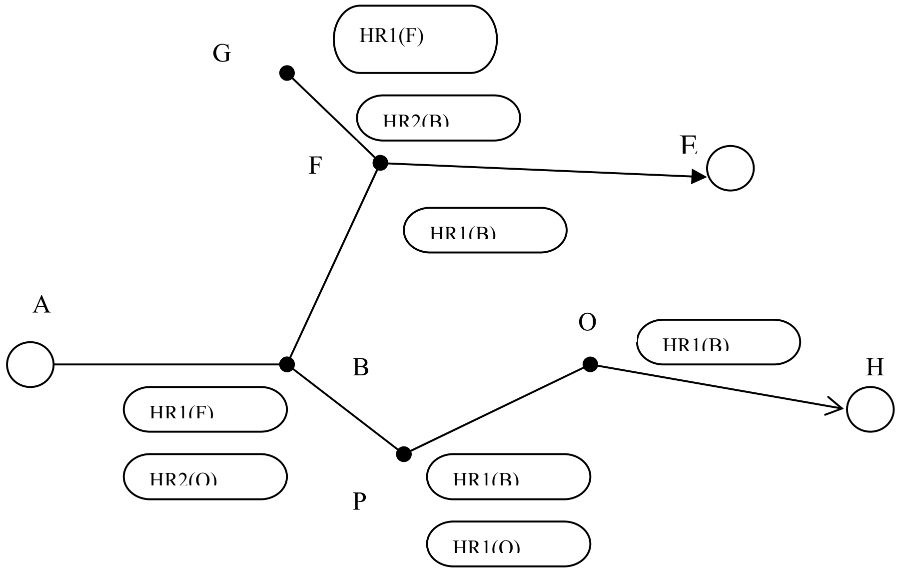

Fig. 3 Information exchange between online nodes

2.1.2. The Process for Resolution

Resolution is the process of collecting the local information, preparing a conflict-free schedule and run the schedule. The procedure registration guarantees that no two Monitors are at a distance of 1-hop, 2-hop. With the coordination of the non-monitor nodes the resolution process allows no two monitors to run the scheduler at the same time.

A monitor, which succeeds the resolution process, becomes a head. The procedure is as follows. Consider the figure 3.0. Let A, E, F are the monitors. Each of these monitors transmits their information through theirs 1-hop neighbors. Node B observes that A is its monitor and collects the information about its monitor id, time when A became a monitor. The Monitor (B)_1 is constructed with the above information and sends it to its 1-hop neighbors C. C constructs Monitor (B)_2 and sends it to its 1-hop neighbors.

Hence all the non-monitor nodes get packets from their 1-hop neighbors, containing information about the active monitors.

The non-monitor nodes analyses the information in the packets and accepts the monitor, which has higher priority as its head. Once this acceptance is received from all of A's 1-hop neighbors, A sends the acknowledgement to its 1-hop neighbors. The 1-hop neighbors reset the state information about its new neighbors and transmit the same to its 1-hop neighbors.

calls the NABS protocol to calculate the slots and then runs the new schedule. The remaining monitor nodes are suspended from transmitting until the resolution process completes and A un-reserves the Broadcast-minislot

2.1.3 Proposed Slot Assignment Protocols

Proc Time_Slot_Allocation(A)
  Begin

//D-2_neighbors – contains the n-hop neighbors list of a node .

//Large_conflict_set(A) contains the list of nodes that donot produce Type 1 or Type2 interfernces with A

//Possible_color_set.—Contains the number of nodes present in Large_conflict_set

// Conflict_free_node . – list of nodes not producing conflicts with node A

//Conflict_node_set – list of nodes producing conflicts with node A

1.0 D-2_neighbors (A) ← Assign 3-hop, 4-hop … n-hop Neighbors list of A

2.0 Large_conflict_set(A)← Find from D- 2_neighbors(A) the largest set of non-conflicting nodes that can transmit along with A.

3.0 Let Possible_color_set(A) ← List of colors used by nodes in Large_conflict_set(A)

4.0 Sort the Possible_color_set(A) in ascending order of their color values.

5.0 Let finished ← false

6.0 For I in Possible_color_set(A) do
{
// Find whether node A fit in slot i
Conflict_node_set(A) ← find list of nodes producing conflict with A in slot i.
if [for each node in Conflict_node_set(A) are found in slots less than I]

then begin
// remove those nodes from the race
Large_conflict_set(A) ← Large_conflict_set(A) – Conflict_node_set(A)
// slot assignment is completed assign the current slot to the new //node . All the conflict producing nodes are assigned the cahnnel atleast //once in earlier slots they are removed from the contention now. Finished ← true

// exit the procedure slot assignment since

Exit(true)
End

//end of if
}// end of fo loop

7.0 if finished = false then
// if not able to allow the node to transmit within the existing schedule then //assign a new slot to the new node by increasing the frame size by 1 Increment current slot_value by 1
Assign slot_value to node A
Conflict_free_node (A) ← Find the non-interference node set of A
Allow the nodes in conflict_free_node (A) to transmit in the current slot_value slot also.
End if
// end of the if
End

Proc Time_Slot_Allocation-2(A)
begin
// Slot_ neighbors (A) contains the list of nodes who are assigned the same slot as assigned to A
// Slot_ neighbors (A,s) contains the list of 1-hop and 2-hop neighbors of A //who are assigned the slot s

1.0. Slot_ neighbors (A) ← Assign the list of nodes, which are transmitting along with A.
2.0. Initialize Flag [1.. N] to false
3.0 For each node I in Slot_ neighbors (A) do
For s = 1 to Frame Length do
Small_ conflict_ set(I) ← List of 1-hop , 2-hop neighbors of I assigned to the slot s
If Small_ conflict_ set(I) = Null then
Assign Slot s to node I
Flag[I] = True;
End if
End For
If Flag[j] = true for all j = 1 to Length (Slot_ neighbors (A)) Then Decrement the Frame Length by one
Else
// Frame length cannot be decreased
End if
End

The above time slot_assignment protocol-1 does not simply increment the slot_value by 1 whenever a new node joins the network. The protocol checks whether the new node produces a non-conflicting schedule with the existing schedule. If so the new node transmits in any of the existing frame slots. The frame length remains unchanged. Moreover, the throughput increases as the number of transmissions increases with the joining of the new node. However, if it is not possible to transmit in the current frame slots, then the slot_value is incremented by one. The new schedule is broadcasted and implemented during the next frame time.
The primary objective of Mobile Adhoc Networks is to decrease the frame size and the secondary objective is to increase the total number of transmission slots. Hence, the slot assignment protocol greedily updates the slot_value for effective channel utilization.

Whenever the node leaves the network, it re-computes the assignment of the slots. This is to decrease the frame length. The leaving node collects the information of all the other nodes transmitting during its own slot. It tries to allocate some slots in the existing frame slots, without disturbing the type1 and type2 interferences principles. If it is possible, one can decrease the current frame length, which results in increase of the throughput of the network. Otherwise, the frame length will not be decrease, and the throughput of the network decreases. The leaving node broadcasts the new schedule to all of its 1-hop neighbors.

3. The New Adaptive Broadcast-Scheduling Algorithm (Nabs).

NABS computes the slot assignments. The NABS Scheduling Algorithm minimizes TDMA frame length and maximizes the channel utilization. The NABS comprises two phases Information Gathering Phase and MAX_IDENT phase. During the Information Gathering Phase, a node constructs the INFO record. During the MAX_IDENT phase, a node X that has maximum number of non-interfering nodes that can transmit along with it is calculated and recorded in OUT. The details of X and its non-neighborhood node details will be recorded in ASSIGN record. After these two phases, the nodes in ASSIGN record were allowed to reserve the current slot. The nodes in ASSIGN record should produce an interference schedule i.e. no two neighbors within their transmission range are allowed to transmit.

3.1. Algorithm NABS

L denotes the search level
MAX record contains the node id
SMin contains the node id which stops only a minimum number of nodes from transmitting along with it
S1 Denotes node with id 1
V denotes the set of nodes willing to transmit during the current frame.
ASSIGN record contains a list of node id's identified in MAX_IDENT phase
JL Denotes a set, which contains the list of all nodes that had already reserved a slot
VL Denotes the set of nodes that had not reserved a Slot.

Step 1. Set the current search level as 0 (L = 0), Jl = Φ

Step 2 // Find the set of nodes willing to transmit
V ← Nodes_ willing_ to_ transmit() and VL ← V

Step 3. Construct INFO Record from the state information of all the nodes in V

Step 4. Repeat steps 5 thru 11 until JL = V or V={Φ}

Step 5. Increase L by 1.

//Find the number of non-Conflicting time slots assignments for network nodes as follows

Step 6. Construct MAX Record and SMin is identified as follows

a)Find Interference_ free_ Schedules(V)

//Compute for each node , the set of non-conflicting nodes set from exempting the 1-hop ,2–hop neighbors of each node in the set
b) Let ni ← Length (Interference_ free_ Schedule (i)

// ni contains the number of nodes in the interference-free schedule when node i transmits.

c) The MAX record contains nodes s1 , s2 s3 , s4 , … sk ordered such that
n1 < n2 < n3 < n4 … < nk

// ni is the length of interference_ free_ Schedule of node i.
//sk is the node that allows more number of nodes to
//transmit along with it. This ultimately improves the
//channel utilization.

d) If Sk is not found in JL Then SMin = Sk
Else
// if sk is assigned a slot earlier then
repeat

// Find a station as follows
i ← k-1
Repeat
SMin ← Si .
If SMin is already assigned a slot in previous levels
then i ← i - 1 // find another node.
Else Node is found SMin ← Si and goto step 7.
End if
Until i >=1.
Endif// SMin contains the id of the node which allowed to transmit in the current slot.

Step 7. Construct ASSIGN record from the ids of the 3-hop, 4-hop … n-hop neighbors of SMin.

Step 8. Sx ← interference_ free_ Schedule (Min)

// Prepare a set of interference_ free nodes set from the
//ASSIGN record.

Step 9. Let JL ← JL U {Sx}// Assign the current slot to nodes in Sx and update the set JL to include the new nodes.
Step 10. Let V ← V - SMin
Step 11. Until JL = V or V={Φ}//Repeat until all the nodes have been assigned a slot at least once.
Step 12. Stop.

4. Analysis

The throughput of the network is defined as the ratio of the number of the successfully transmitted slots in one frame to the frame length. The overhead induced by the adding/removing a link has ignored. The throughput analysis assumes heavy traffic conditions. The channel utilization has defined as follows

$$\rho = \frac{\sum \rho j}{N} \quad \text{where } j = 1 \text{ to } N$$

$$= \frac{1}{NM} \sum_{i=1}^{M} \sum_{j=1}^{N} (Sik)[11]$$

Each station must be able to transmit at least once in a frame. For a given Mobile Ad Hoc network, the minimum frame length depends on the topology of the network and is generally unknown. However, a tight lower bound for a frame length has found, thus allowing one to estimate the minimum required frame length. The degree of a vertex i is defined as the number of edges incident to it and denoted as deg (i).

The Maximum/ Minimum number of transmissions depends on the number of 1 hop, 2-hop … n-hop neighbors and the degree of the vertex. Let D denote the degree of the network and M denote the number of slots per each frame. Let each node have at least one K-hop neighbor, where K>2.Then each node can have a minimum of K/3 number of interference free node schedule. If D > 2 then, each slot can be allotted to at least D nodes. The maximum number of transmissions in a frame is M*(K/3) *D. Each node need not have degree D. let us assume for some constant K1 <=M and K1>0, there are K1*D number of transmissions per each frame, Where K1*D <= M*(K/3)*D (1)

Then the guaranteed throughput

$$\rho \approx \frac{K1*D}{M*N} \quad \text{where } K1 \le M*(K/3) \text{ and } K1>0,\ D > 1$$

$$\approx \frac{C*D}{N} \quad \text{where } C= (K1/M) \qquad (2)$$

The Frame length depends on the hop degree K, Degree D of the network and the number of nodes N in the network. Hence, the throughput depends on M the frame Length, N the number of nodes, K the hop degree of the network, D the degree of the network.

The guaranteed throughput is

$$\approx \frac{K * 1}{3 * N} \quad \text{when } D = 1$$

$$\approx \frac{C * D}{N} \quad \text{when } D > 2 \qquad (3)$$

5. Results.

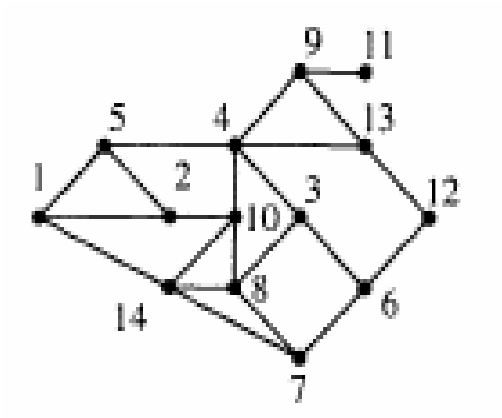

Fig. 4 Example Network

BSP[8] produces the schedule in Table 1, where r stands for reserved and - for blocked. NABS produces the schedule in Table 2. In table 1 the length of frame M = 14 and 34 maximum transmissions by all stations. The guaranteed throughput is 0.1785. Were as the NABS required only 7 slots per frame, i.e. M = 7 and 20 maximum transmissions by all stations which is shown in Table 2. The guaranteed throughput is 0.2045. This represents an improvement of approximately 10% of channel utilization over the method proposed in [8]. The NABS algorithm is tested for different topologies of the packet radio networks under heavy traffic conditions.

The Guaranteed Throughput = 0.2045 for N=14 , D = 4
=0.16 for N = 100 , D=6 .

This shows that as N and D increases, the throughput decreases. This is because of the more number of interference nodes. Some of the results are shown in table 2. The relationship between K1 / M and D has be seen in the fig. 5.

The curve in Fig 6 indicates that performance of NABS decreases as the degree D increases. For larger N and D > 8, the number of interferences between nodes increases and a slot can not be shared by more number of nodes. Hence, the value of K1 decreases. If number of transmissions per slot decreases, the total number of slots increases and hence M increases.

This results in the decrease of the channel utilization. The curve in Fig 7 shows the performance of conventional TDMA, chalmatac's schedule, Ju's Schedule, Oikonomou's schedule, TTR schedule and 802.11.

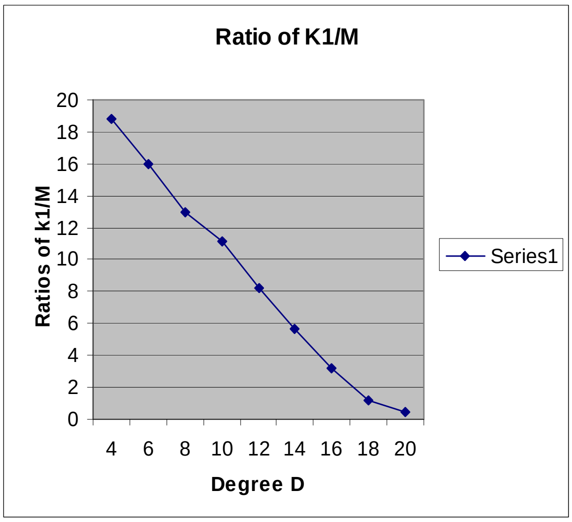

Fig. 5 Relationships between K1/M and Degree D

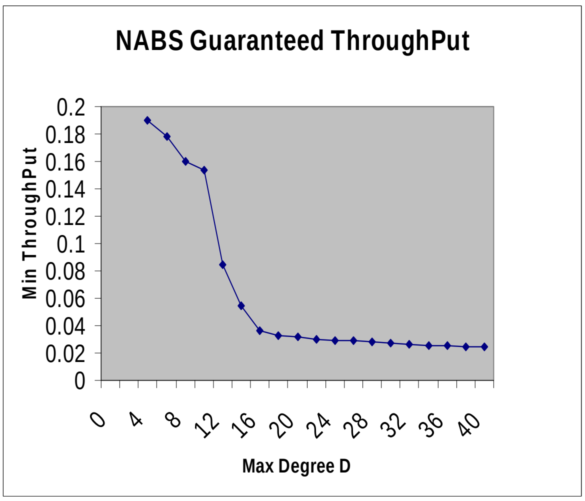

Fig. 6 The Guaranteed throughput with different D and N = 100

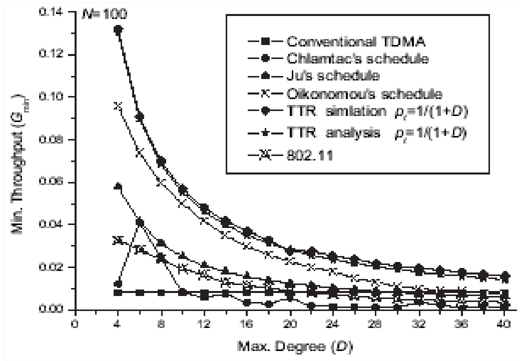

Fig. 7 The Guaranteed Throughput N = 100 [12]

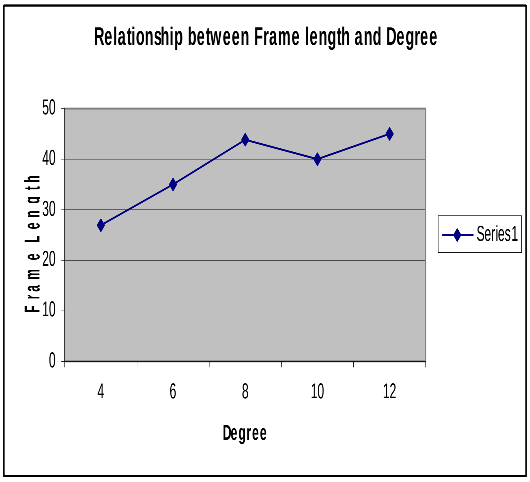

Fig 8 Relationship between frame Length and Degree D and N= 100

6. Conclusion

NABS depends on the state information of all of its neighbors. In this paper, through theoretical analysis we derive the guaranteed throughput and the maximum throughput. Simulation results demonstrate that this new protocol outperforms other Conventional TDMA, chalmatac's schedule, Ju's Schedule, Oikonomou's schedule, TTR schedule and 802.11. The curve in Fig 6 shows that NABS always performs better than the schedules mentioned in Fig 7.

The fig 8 gives the effects of the parameters like frame length and degree on the throughput. These results state that as the degree increases, the frame length increases. As the number of outgoing links to the nodes increases, the more are the interference nodes and hence the number of nodes that can transmit in a slot decreases. This leads to the increase in the frame length. NABS was simulated over the network of N=100, D= 4,6,8,10,12. The max_degree of the network has assumed to be the minimum number of outgoing links for each node in the network. The degree of the network has assumed to be the maximum number of outgoing links of any node in the network. It had observed that as the Max_ degree increases, the number of nodes reachable from a node also increases. This leads to decrease in the throughput, as the number of interferences amongst the nodes increases with the increase in the degree of the network. The network is simulated for N=100 .

S/nd	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	R	-	R	-	-	-	-	-	-	-	R	-	-	-
2	-	R	-	-	-	R	-	-	R	-	-	-	-	-
3	R	-	R	-	-	-	-	-	-	-	R	-	-	-
4	-	-	-	R	-	-	R	-	-	-	-	-	-	-
5	-	-	-	-	R	R	-	-	-	-	R	-	-	-
6	R	-	-	-	-	R	-	-	R	-	-	-	-	-
7	-	R	-	-	-	-	R	-	R	-	-	-	-	-
8	-	-	-	-	R	-	-	R	-	-	R	R	-	-
9	R	-	-	-	-	R	-	-	R	-	-	-	-	-
I0	-	-	-	-	-	-	-	-	-	R	R	R	-	-
11	-	-	-	-	R	-	-	R	-	-	R	R	-	-
12	-	-	-	-	R	-	-	R	-	-	R	R	-	-
13	-	R	-	-	-	-	-	-	R	-	-	-	R	-
14	-	-	-	-	-	-	-	-	-	-	R	R	-	R

Table 1: Results of the BSC algorithm in [8] for the figure 4 S= Slot Number, nd=nodes

Nd /S	1	2	3	4	5	6	7
1	-	-	R	-	-	R	-
2	-	R	-	-	-	-	-
3	-	-	-	-	-	R	-
4	-	-	-	-	-	-	R
5	R	-	-	-	-	-	-
6	-	-	R	-	R	-	-
7	-	R	-	-	-	-	R
8	R	-	-	-	-	-	-
9	-	R	R	-	-	-	
10	-	-	-	-	R	-	-
11	R	-	-	-	R	R	-
12	R	-	-	-	-	-	-
13	-	-	-	R	-	-	-
14	-	-	-	R	-	-	-

Table 2: Results of the proposed NABS Algorithm for the figure 4

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