

Improved Reliable 1-Hop Broadcast in Mobile Ad Hoc Networks

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Abstract— Among Many fundamental communication primitives in mobile ad hoc networks, 1-hop broadcast plays an important role in which a message from the source node is delivered to *all* nodes within the source node's transmission range. Despite the importance of it, 1-hop broadcast is not easy to accomplish due to collisions in wireless networks known as Hidden Terminal problem. This paper presents a MAC protocol that guarantees 1-hop broadcast with efficiency by allowing as many simultaneous executions of the communication as possible without collisions. The proposed algorithm utilizes control packets that prevent data packet collisions, and at the same time, make the simultaneous communications possible to improve the network throughput. Simulation results support the effectiveness of the proposed algorithm in terms of less collisions and higher transmission success ratio than existing protocols.

Keywords— Mobile ad hoc networks, broadcast, reliable communication, 1-hop broadcast, collision.

I. INTRODUCTION

This A Mobile Ad Hoc Network (MANET) consists of a set of wireless mobile hosts (or *nodes*) that are free to move in any directions at any speed. A MANET does not require any preexisting fixed infrastructures, and therefore it can be built on the fly. Since nodes in MANET operate on batteries and have a limited transmission range, minimizing unnecessary traffic is essential to improve the network lifetime and throughput.

Due to the nature of a wireless network, a transmission in wireless networks is basically a 1-hop broadcast, that is, a signal transmitted from a node (source node) reaches all nodes within its transmission range (*neighbors* of the source node). Many important algorithms in MANETs heavily depend on the performance of 1-hop broadcasting [11, 12, 13, 14, 15]. Some significant applications of 1-hop broadcast are:

- 1) Reactive routing algorithms in MANETs [21, 22, 23, 24].
- 2) Proactive routing algorithms that are based on Distance Vector Routing or Link State Routing [16, 17, 18, 19, 20].
- 3) Topology control [25, 26, 27].
- 4) Algorithms based on hierarchical organization of nodes [28, 29, 30].

The algorithms described above work correctly provided that the 1-hop broadcasting is *reliable*, i.e., packet delivery from the source to *all* its neighbor nodes is guaranteed.

Otherwise, inaccurate and/or insufficient information may cause severe degradation of the algorithms and therefore undesirable results.

Achieving a reliable 1-hop broadcast in wireless networks is not easy due to the collisions caused by a phenomenon known as *Hidden Terminal Problem* [1]. If a transmission is just between two nodes (point-to-point communication), then RTS/CTS protocol can be used [16]. However, point-to-point communication will be extremely inefficient and often useless if it is used for 1-hop broadcast in wireless mobile networks. Another degradation of network throughput occurs when nodes cannot explore possible simultaneous transmissions. An example of this type is the Exposed Terminal Problem [2] that prevents two neighbor nodes from successful simultaneous transmission.

Many communication algorithms proposed thus far are based on the single-channel MAC protocols. However, IEEE 802.11 standard for wireless LAN provides multiple channels for communication between nodes in the network [1]. One of the benefits of having multiple channels is that multiple transmissions on different channels can take place simultaneously without causing any collision and contention between the transmissions [2, 3, 4, 5].

This paper presents a reliable 1-hop broadcasting algorithm, Improved Reliable 1-hop Broadcasting (IROB), that guarantees the delivery of broadcast message from the transmitting node to all nodes within its transmission range. Similar to EROB [32], IROB uses three different channels, one for data packets transmissions and two for control packet transmissions to prevent the collision. IROB uses different transmission ranges for control and data transmission to achieve as many simultaneously transmissions as possible. Simulation results show that IROB outperforms naïve algorithm that does not provide any precaution to prevent collisions and other algorithm that implement CSMA/CA.

The rest of the paper is organized as follows. Section 2 explains terminology and related works for the paper. New 1-hop broadcasting algorithm is presented in Section 3 followed by simulation result in Section 4. Finally, conclusion and discussion will be presented in Section 5.

II. BACKGROUND AND RELATED WORKS

Suppose node S in Figure 1 is currently transmitting a packet. Also suppose node V wants to transmit a packet as well. If V knows S is transmitting, V will not start its own transmission, since if it does, it causes collision at D. However, since node V is not within the transmission range of S, V cannot recognize that S is transmitting. Hence, V initiates its transmission, which causes collision at node D. This problem is known as the Hidden Terminal problem [1]. To avoid the Hidden Terminal problem, RTS-CTS protocol was proposed [16]. Note that RTS-CTS protocol is for point-to-point (or *unicast*) communications, i.e., communication between two nodes. However, if the communication is (1-hop) broadcast, the Hidden Terminal problem causes more serious problem than unicast.

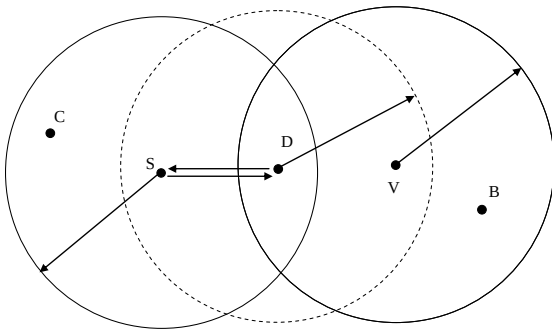


Figure 1. An example of the Hidden Terminal problem.

It is observed in Figure 1 that transmissions from S to C and from D to V can be done simultaneously, if they are unicasts. However, since D and S are within each other's transmission range, they cannot explore this simultaneous transmission if they use RTS-CTS protocol. This is an example of the Exposed Terminal Problem [2].

Park and Palasdeokar [8] have developed a reliable 1-hop broadcasting algorithm called ROB that uses only one channel that is for both control packets and data packets. ROB does not require any control packet transmission prior to data packet transmission. When a node S transmits a data packet, only those nodes in S's transmission range that detected a collision transmit NACK message indicating that they did not receive the packet. Therefore, if S did not receive any NACK or collision, the 1-hop broadcast could be regarded as completed. Otherwise, S continues transmitting the same data packet until it does not receive any NACK or collision.

Lembke et al. [9] proposed two reliable 1-hop algorithms: one is proactive and the other is reactive. The reactive algorithm utilizes two channels and control packet called "whistle" which is similar to BIP in the proposed algorithm.

Park and Anderson [10] have proposed a guaranteed 1-hop broadcasting algorithm called GOB that resolves the broadcast complete problem [8] and whistle propagation problem [9]. GOB uses a control packet BIP to prevent possible collisions, and therefore, improve network throughput. However, nodes in their algorithm do not explore simultaneous executions of 1-hop broadcast either.

Although motivated by and uses similar terminology and concepts of the algorithms in [8, 9, 10], the proposed algorithm presents a significant improvement over the algorithms by exploring parallel executions of the 1-hop broadcasting whenever possible, which produces far better performance in the network throughput.

III. IMPROVED RELIABLE 1-HOP BROADCAST (IROB)

This section presents a new 1-hop broadcasting algorithm, called Improved Reliable 1-hop Broadcasting (IROB) that improves EROB [32] with more transmission success ratio and less collisions.

Assumptions made in this paper is that each node is capable of implementing CSMA/CA [31].

IROB uses the basic notation, definition and implementation similar to that of EROB and GOB [10], as described below. Two types of packets are used in IROB: *control packets* and *data packets*. Data packets contain the data that are to be 1-hop broadcast, and control packets are used to enhance the efficiency of the data packet transmission. Although control packets, such as RTS/CTS [16], may not be essential, the network throughput is usually higher with them due to their control over packet collisions.

IROB uses only a single type of control packet called *Broadcast-In-Progress* (BIP in short) to prevent collisions. A BIP is produced and used in two cases.

- 1) Prior to 1-hop broadcast of a data packet, a node transmits a BIP to secure not only the broadcast area but also broadcast threatening area to prevent any possible collision.
- 2) On receiving a BIP, a node that is currently involved in any other communication generates and transmits a BIP to warn other nodes in its broadcast threatening area not to initiate data packet transmission.

A BIP consists of unique bit pattern that distinguishes it from other types of packets. In addition to the actual data, a data packet contains other information such as the source's ID, packet ID, and the size of the data packet.

Although, IROB presented in this paper is only for static nodes. For the case of nodes with mobility, refer to EROB [32]. Since IROB is improved from EROB, EROB is described in section A in detail, followed by Section B where IROB is presented.

A. EROB

To reduce the probability of collisions, and to simplify the collision prevention process, EROB uses three different channels. CH_{BIP} and CH_{DATA} are dedicated to control packet (i.e., BIPs) and data packet transmissions, respectively. The usage of the third channel CH_{COL} is to prevent the BIP Propagation Problem that will be explained shortly. Since different types of packets use different channels, collisions can occur only between the same type of packets, not between different types.

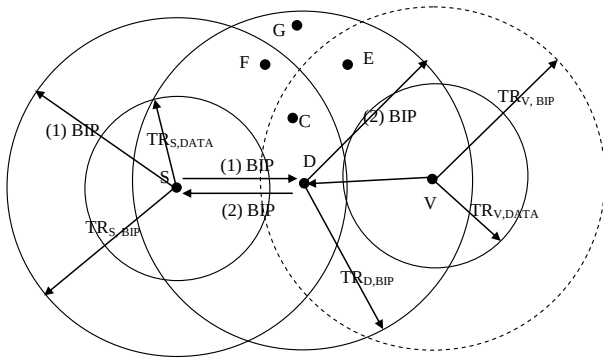


Figure 2. Both S and V transmit a BIP, which causes collisions at C and D.

BIPs in EROB prevent data packet collisions as follows. Refer to Figure 2. Recall that BIPs are transmitted only along CH_{BIP} and data packets are transmitted only along CH_{DATA} . Suppose node S in Figure 2 has a data packet to be 1-hop broadcast. Then, prior to data transmission, S prepares and transmits a BIP with TR_{MAX} ($= TR_{BIP}$) to inform the nodes in its transmission range (C, D, and F in this case) with its intention of immediate data packet transmission. On receiving the BIP, if a node is currently not involved in any communication, then the node remains silent. Otherwise, i.e., if the node is currently involved in any other communication, it transmits a BIP to warn S not to transmit data packet, since S's transmission may cause collision at the node. On receiving the BIP, S refrains itself from transmitting. Following two examples illustrate this case.

Case 1) Suppose there is a node in S's transmission range that is involved in data packet transmission. Then, the node prepares and transmits a BIP to warn S not to transmit data packet, since if S does, it would cause data packet collision at the node. If there are two or more nodes that are involved in data transmission in S's transmission range, they all transmit BIPs to warn S. In this case, although S would hear a garbled message (i.e., garbled BIPs) that is not possible to decode correctly, S interprets the situation correctly and not to transmit data packet.

Case 2) Suppose there is more than one node that has data for 1-hop broadcast. For example, suppose both S and V in Figure 2 have data for 1-hop broadcast. Then, as described above, they transmit BIPs prior to data transmission to prevent collisions. Since the two BIPs collide at C and D resulting garbled message, C and D cannot decode the BIP correctly. In this case, C and D realize that the garbled signal in CH_{BIP} is due to the simultaneous reception of BIPs, and transmit BIPs to warn both S and V for possible collision. Note that in this case S also receives a garbled message in CH_{BIP} . Also note that if there is only one node (that is either C or D) in $TR_{S,BIP} \cap TR_{V,BIP}$, the node would transmit a BIP that is heard by S. In this case, S would not transmit its data packet, either. That is, whether S hears a BIP or collision, it would not transmit data packet.

Although BIPs are very useful, they also may cause a serious problem, called *BIP propagation problem*, similar to whistle propagation problem [9]. When a node detects a collision in CH_{BIP} , it transmits a BIP only along CH_{COL} indicating that the BIP is the response to the first BIP collision. For example, nodes C and D in Figure 2 transmit a BIP only along CH_{COL} when they detect a collision caused by two BIPs from S and V. When E and F receive the garbled BIP along CH_{COL} , they know it is not the first BIP collision because it is along CH_{COL} , and do not transmit any BIP. Therefore, the BIP is blocked at C and D, and is not propagated to G as well as not back to C and D. Note that regardless of the reception along CH_{COL} , if a node detects a collision in CH_{BIP} , the node transmits a BIP along CH_{COL} .

Good communication algorithms should provide advantages such as 1) power conservation in packet transmission, 2) low probability of packet collision, and 3) better network throughput by allowing as many simultaneous transmissions as possible. In order to achieve these, a node in EROB uses different transmission power levels depending on its current status (that is, either sending or receiving) and the types of the packet it transmits. Data transmitting nodes use TR_{MAX}

(maximum power level) for BIP transmission and $\frac{TR_{MAX}}{2}$ for

data packet transmission. On the other hand, data receiving

nodes transmit BIPs, if necessary, with $\frac{TR_{MAX}}{2}$. Following

example shows how EROB accomplishes better network throughput by controlling the transmission range.

Refer to Figure 2. If both S and V transmit data packets with TR_{MAX} , there will be a collision at C and D. One possible solution is to let node D, on receiving the BIP, prepare and transmit its own BIP with TR_{MAX} so that both S and V hear it and refrain themselves from transmitting data packets. This solution is simple, but not productive since no node can transmit any data. The approach EROB takes to improve network throughput is to reduce the transmission

range for data packets to $TR_{DATA} = \frac{TR_{BIP}}{2} = \frac{TR_{MAX}}{2}$. With

this transmission range, there will be no overlapped area, i.e., $TR_{S,DATA} \cap TR_{V,DATA} = \{\}$, so that both S and V may be able to transmit their data packets at the same time without causing any collision. Our simulation shows that the network throughput has been improved considerably with this scheme.

Incorporating schemes described above, EROB at each node executes the following phases. Note that *transmission* and *1-hop broadcast* are synonymous in wireless networks.

Phase 1) Prior to 1-hop data packet broadcast, S listens to the channels, CH_{BIP} , CH_{DATA} , and CH_{COL} for any on-going transmission. Then, the following two cases can occur.

Case 1) S detects packet transmission in any of the three channels. This indicates that there is an on-going transmission in S's transmission range. Therefore, if S starts transmitting, it may cause collision. In this case, S waits a random amount of time, and then starts Phase 1 again.

Case 2) S does not hear any on-going packet transmission in any channel. In this case, S will go to Phase 2.

Phase 2) S transmits a BIP packet (designated by (1) in Figure 3) along CH_{BIP} with the maximum power TR_{MAX} to inform its neighbor nodes with its intension of immediate transmission of data packet. During the BIP transmission, if S detects any on-going transmission except its transmission in any of three channels, then S immediately stops transmitting the BIP and enters Phase 1. Otherwise, after transmitting the BIP, S enters Phase 4. All other nodes including nodes in $TR_{S,MAX}$ enter Phase 3.

Phase 3) A node in $TR_{S,BIP}$ either receives a BIP or detects a collision along CH_{BIP} , depending on the number of BIP transmitting nodes within its TR_{MAX} . For example, suppose both S and V in Figure 3 transmit a BIP simultaneously. Then, node F hears the BIP from S, but D detects a collision since it receives both BIPs from S and V. Depending on the current status, a node, say N in $TR_{S,BIP}$, $N \neq S$, falls into one of the following three cases.

Case 1) N is currently *transmitting* a data packet. Note that N cannot be within $\frac{TR_{S,BIP}}{2}$ ($= TR_{S,DATA}$), since if it is, S must

have heard the data packet transmission from N in Phase 1 and could not enter Phase 2. Therefore, in this case N must be in the broadcast threatening area of S as shown in Figure 4(a). If S starts transmitting data packet, there will be a data packet collision at the nodes, for example C, in $TR_{S,DATA} \cap TR_{N,DATA}$. Therefore, to avoid any data packet collision, N immediately transmits BIP along CH_{COL} with power level of TR_{MAX} to warn S not to transmit.

If N is receiving a signal along CH_{COL} only, this implies that N is out of $TR_{S,MAX}$. Because the signal is to prevent BIP propagation, N ignores the signal and continues transmitting the data packet.

Case 2) N is currently *receiving* a data packet. In this case, the location of N could be anywhere within $TR_{S,BIP}$ ($= TR_{MAX}$). To avoid a collision, node N transmits a BIP along CH_{COL}

with power level of $\frac{TR_{MAX}}{2}$. Then, depending on the location of N, the following two subcases can occur.

Subcase 1) N is within $\frac{TR_{S,MAX}}{2}$ ($= TR_{S,DATA}$). Assume that

N is receiving data packet from node, say V, as shown in Figure 4 (b). (Note that V is within the broadcast threatening area of S, and cannot be within $\frac{TR_{S,MAX}}{2}$, since if it is, S

must have heard V transmitting data during Phase 1 and could not enter the Phase 2). If S transmits data packet, there would be a collision at node N. Therefore, BIP transmission from N

with transmission power level of $\frac{TR_{MAX}}{2}$ will prevent S from transmitting data. As a result, there will be no collision.

Subcase 2) N is within S's broadcast threatening area (i.e., between $\frac{TR_{S,MAX}}{2}$ and $TR_{S,MAX}$) as shown in Figure 4 (c).

In this case, transmission of BIP from N with power level of $\frac{TR_{MAX}}{2}$ would not reach S, which allows simultaneous

transmissions from both S and V without collision. This may enhance the network throughput.

Case 3) N is not involved in any data packet transmission. In this case, N can be one of the following two subcases.

Subcase 1) V is receiving a single BIP. This implies that there is only one node (S in this case) to be transmitting in V's transmission range. Since there is no possibility of collision, V keeps silent and does not do anything.

Subcase 2) V is detecting a collision of BIPs in CH_{BIP} . This implies there is more than one node trying to transmit in V's transmission range, which may cause collision at V. To prevent the collision, V transmits a BIP along CH_{COL} with the power level of TR_{MAX} to warn the nodes not to transmit.

Phase 4) After transmitting a BIP, two cases can occur for S.

Case 1) S detects a BIP or a collision of BIPs in CH_{BIP} (case when another node(s) in $TR_{S,MAX}$ is currently transmitting a data packet), S detects a BIP or a collision of BIPs in CH_{COL} (case when there is a node, for example node D in Figure 3, that received more than one BIP). In this case, S stops and enters Phase 1.

Case 2) S does not detect any signal in any channel. In this case, S can go ahead and transmits its data packet with

$\frac{TR_{MAX}}{2}$. During the data transmission, if S detects a BIP or

a collision in CH_{BIP} , it will transmit a BIP immediately to suppress the attempt of transmission from other nodes that may cause collision (In this case, S is N in Case 1 of Phase 3). Also, during the data transmission, if S detects data packet collision, it immediately stops transmitting data packet, and enters Phase 1 (Note that this case may not happen, since EROB in this section assumes no node mobility).

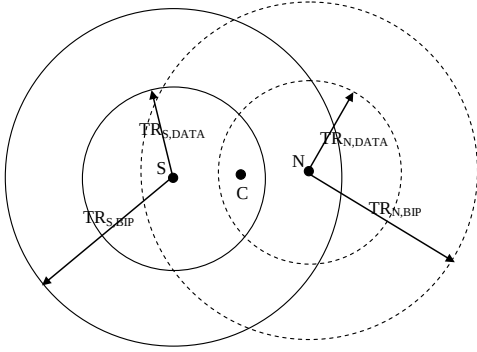
All other nodes that detect a collision of BIPs in CH_{COL} remain silent since the collision is the result of BIP propagation. Summary of EROB is presented in Figure 5.

B. IROB

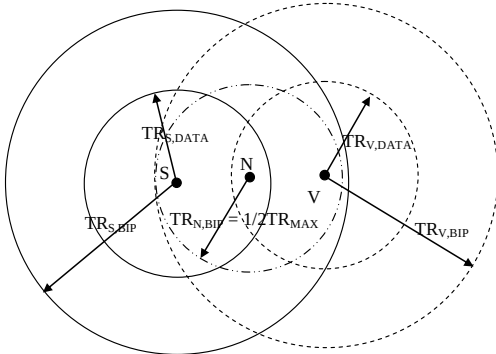
This section presents the proposed algorithm, *Improved Reliable 1-Hop Broadcast* (IROB). Since IROB is basically very similar to the EROB, this section explains only the improvement over EROB.

Refer to Figure 2, where two nodes S and V have data to be 1-hop broadcast and D is not involved in any communication. Suppose both S and V transmitting a BIP simultaneously. In EROB, on receiving the BIPs, D detects collisions in CH_{BIP} and transmits a BIP that reaches both S and V to prevent them to transmit their data packets. Note that in this case, both S and V can transmit their data packet without causing any

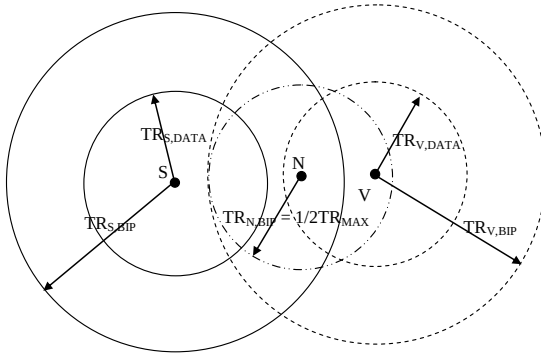
collision, since they are not within each other's data packet transmission ranges of $\frac{TR_{MAX}}{2}$.



(a) N is within broadcast threatening area of S and is transmitting data packet.



(b) N is within $\frac{TR_{S,MAX}}{2}$ and receiving data packet.



(c) N is within broadcast threatening area and is receiving data packet

Figure 4. On receiving a BIP from S, three different responses of node N depending on its location and status.

Therefore, if D transmits its BIP with the transmission ranges of $\frac{TR_{MAX}}{2}$, not with TR_{MAX} as in EROB, the BIP will reach neither S nor V, and they can transmit their data packets safely. This allows more simultaneous transmissions in IROB.

IV. SIMULATION

Three algorithms have been tested and compared in the simulation. The first algorithm is based on CSMA/CA protocol in which a node starts transmitting data packets only if there is no on-going transmission. Otherwise, it waits a random amount of time and tries again. The second algorithm is EROB, and the third is IROB.

The simulation environment is similar to the one in EROB [32]. The size of the network in our simulation is 2000×2500 , and transmission range is 300. At the beginning of simulation, each node is assigned random starting and destination positions with randomly chosen speed of between 0 and 100. Once a node reaches its destination, the destination becomes new starting point and the new destination is assigned with new speed. Nodes move straight between starting and destination point. In our simulation, it is assumed that every node always tries to 1-hop broadcast to generate hostile environment. Data packet transmission duration is 10 and BIP is 2, which seems reasonable since BIP size is much smaller than data packet. Each simulation lasts 200 unit times.

First simulation has been performed to discover the relationship between the number of nodes and the number of collisions generated by three algorithms. The result is shown in Figure 8. The number of collisions of IROB is larger than that of EROB.

Second simulation is to find out the relationship between the number of nodes in the network and the number of successful transmissions of the three algorithms, and the result is shown in Figure 9. In this experiment IROB outperforms both CSMA and EROB, although IROB is slightly better than EROB.

V. CONCLUSIONS

1-hop broadcast is a fundamental communication primitive in any networks, especially in wireless networks where every transmission is a 1-hop broadcast by nature.

We have presented an algorithm, called EROB, that guarantees the completion of 1-hop broadcast in mobile ad-hoc networks.

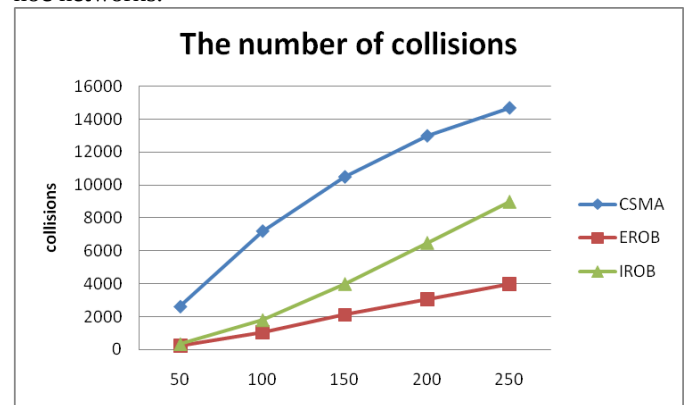


Figure 8. The number of collisions in three protocols.

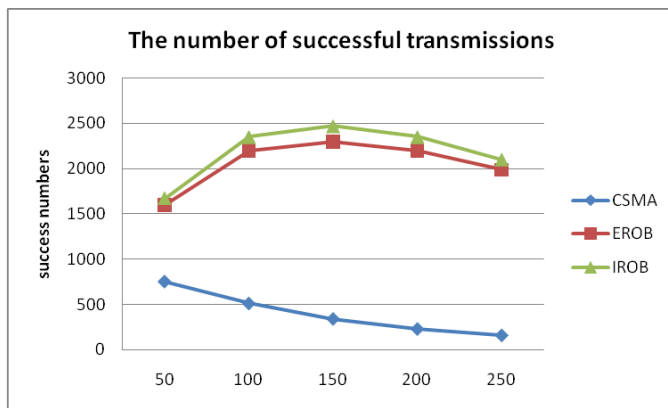


Figure 9. The number of successful transmissions.

A node implementing EROB uses different transmission power levels depending on its current status and the type of the communication it is currently involved. Broadcasting nodes transmit BIPs with transmission range of TR_{MAX} (maximum power level) and data packets with $\frac{TR_{MAX}}{2}$, and receiving nodes transmit BIPs, if necessary, with power level that is enough to reach $\frac{TR_{MAX}}{2}$. Because that the diameter of transmission range in EROB is about the half of possible maximum size, this scheme provides many advantages including 1) power saving due to smaller transmission range, 2) less collision with less number of nodes in transmission ranges, and 3) better network throughput via more simultaneous transmissions.

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