Multipath Routing and Multiple Description Coding in Ad-hoc Networks: A Simulation Study[1]

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ABSTRACT

The nature of wireless multihop ad-hoc networks makes it a challenge to offer connections of an assured quality. In order to improve the performance of such networks, multipath routing in combination with Multiple Description Coding (MDC) has been proposed. By splitting up streams of multimedia traffic into several substreams (called descriptions), by sending these substreams along different paths from the source to the destination, and by reassembling them again at the destination, the quality of the received stream may be improved as compared to the single-description, single-path case. In this paper we present a simulation study of the combination of MDC and multipath routing from a network perspective with a realistic medium access control protocol (IEEE 802.11) and a widely used routing protocol (Dynamic Source Routing with our own multipath extensions). Our simulations show that for most of the cases considered, the combination of multipath routing and MDC does not perform better than single-path routing and a single description in IEEE 802.11-based networks.

Categories and Subject Descriptors

C.2.2 [**Computer–Communication Networks**]: Network Protocols – *routing protocols.*

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design – *wireless communication*.

General Terms

Performance.

Keywords

Multipath routing, multiple-description coding, simulations, wireless ad-hoc networks.

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1. INTRODUCTION

The nature of wireless multihop ad-hoc networks with a shared medium, the lack of a central authority for scheduling packets, a potentially low bandwidth, and mobility of the nodes makes it a challenge to offer connections of a quality sufficient for real-time applications and multimedia (voice or video). A potentially promising approach to this problem is to establish multiple paths between the source and the destination of a traffic stream and to use coding schemes that take advantage of the existence of multiple paths. One such coding scheme is Multiple Description Coding (MDC), in which a video stream is encoded into multiple substreams (*descriptions*). Receiving only one description is already acceptable for the receiver, but correctly and timely receiving additional streams adds to the quality. There is no priority among the descriptions, they all play equivalent roles. The aim of this simulation study is to assess whether the combination of multipath routing and MDC does indeed improve the network performance.

It is a-priori unclear whether the combination of multipath routing and MDC has a positive effect on performance. On the one hand, with MDC, even when some but not all of the descriptions experience contention on their routes, or worse yet, find their routes broken, the result may still be acceptable to the destination node. In addition, with MDC, less bandwidth requirements are imposed to the routes. On the other hand, since the multiple paths start at the same source and end at the same destination, they will interfere, even though they are node-disjoint.

Recent studies in this area have focused on developing multipath routing protocols for ad-hoc networks which are either totally new [6, 8] or which are based upon existing single-path routing protocols [10], and on developing coding schemes for multipath topologies [3, 9]. However, the first studies mainly focus on the efficiency of the protocols proposed, and the second focus on the coding itself rather than on the characteristics of the networks that have to support it. As a result, little attention has been paid in this context to the influence of the Medium Access Control (MAC) protocol, the routing protocol (i.e. using static routes), or even the network topology. Here we take into account protocols such as Dynamic Source Routing (DSR) with our own extensions for

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multipath as the routing protocol, IEEE 802.11 as the MAC protocol, and specific network topologies. In other words, this is a study done from a network perspective instead of a coding perspective. We do not intend to propose a new multipath routing protocol.

This paper is organized as follows. After discussing related work in Section 2, we give a description of our model and of its simulation implementation in Section 3. Section 4 contains our simulation setup, and in Section 5 we present the results of the simulation of four scenarios. In Section 6 we draw some conclusions and we point out directions for future research.

2. RELATED WORK

In [12], a multipath extension to DSR is presented that tries to find (nearly) node-disjoint paths between nodes. In addition, the performance of MDC with two descriptions is compared to that of Single Description Coding with a lower data rate (SDC1) in order to account for the overhead of MDC, and with the same data rate (SDC2). With MDC, frames consist of two packets, one for each description, and a received frame is considered good/acceptable/bad if two/one/zero of its packets are received correctly and timely. In models with mobility, simulations in [12] show that SDC1 has the smallest number of bad frames and SDC2 the largest, with MDC in the middle. Our work differs from [12] in that we do not employ a routing protocol optimized for multipath/MDC, that we explicitly look for static scenarios in which MDC might perform better than SDC, and that we use another performance metric (see Section 3.5). Contrary to the findings in [12], we find that in our scenario with mobility, MDC performs worse than SDC with an equal bit rate.

In [7], the capacity of wireless ad-hoc networks with IEEE 802.11 is assessed with simple mathematical derivations and simulations. In particular, it is found that in principle, in a chain topology, the maximum throughput between the end points in the absence of other traffic is a fraction of 0.25 of the nominal net (i.e., without overhead) WLAN bandwith. Also grid and random topologies are considered. A general conclusion is that the capacity of the network scales well if communication exhibits locality, and that IEEE 802.11 does a reasonable job in the overall scheduling of packets.

3. MODEL DESCRIPTION

In this section, we describe the system, mobility, connectivity, workload, and routing models as well as the performance metric employed. We also describe how we have implemented these models in OPNET [11].

3.1 System and Mobility Model

We consider an ad-hoc wireless network with some number of nodes, all of which are static or move randomly in a rectangular playfield. When the nodes move, they do so independently according to the Random Waypoint Mobility Model [1]. In this model, nodes move along a path of randomly chosen waypoints in the playfield. Between successive waypoints, nodes move in a straight line with a constant speed drawn (for each “leg”) from a uniform distribution $[v_{min}, v_{max}]$ with $0 < v_{min} < v_{max}$. When a node arrives at a waypoint, it pauses for a random amount of time, drawn (at each waypoint) from a uniform distribution $[t_{min}, t_{max}]$ with $0 \leq t_{min} \leq t_{max}$. All pause times are mutually independent, and independent of the node waypoints and speeds. The boundary values for the speed (viz., v_{min} and v_{max}) and for the pause times (viz., t_{min} and t_{max}) are the same for each node. At t=0, the nodes are distributed randomly, uniformly, and independently across the playfield, and each node starts with a pause time. We use the implementation of the Random Waypoint Mobility Model from NIST [2] with only minor modifications.

3.2 Connectivity Model

In our connectivity model, two nodes are able to communicate if the distance between them does not exceed some predefined, constant, *communications range*. We let the *interference range* be equal to the communications range. The MAC protocol used is that of IEEE 802.11b, which employs Carrier Sense Multiple Access with Collision Avoidance and with Request To Send/Clear To Send (RTS/CTS). An implementation of the protocol is readily available at [11].

3.3 Workload Model

The workload model is as follows. Starting at t=0, selected nodes inject traffic into the system in the form of multimedia streams each destined for a single other node. Using MDC, such a multimedia stream is split up into a fixed number F of packetized substreams or *flows*, each corresponding to a different *description* of the stream. If F is equal to 1, no MDC is applied, and the packets of the only flow are the packets of the original multimedia stream. Then, these packets are all of a fixed size S and have a fixed interarrival time A.

If F is larger than 1, each flow consists of the same number of packets as when F is equal to 1, but all these packets are of size S/F. In addition, rather than generate packets for all flows simultaneously, we assume that the encoder generates packets in a round robin fashion for the flows with fixed interarrival times of length A/F. As a consequence, the interarrival times of the packets of a single flow are still of length A. So in our idealized model, traffic is injected at the same rate into the system independent of the number of descriptions used, or in other words, the use of MDC does not increase the total amount of data. The ensemble of F packets (one for each flow) sent within a time interval A is called a *batch.* Each packet contains a *stream identifier* and a *flow identifier*.

3.4 Multipath Routing Model

The multipath routing protocol we use is a modified version of the existing implementation of DSR version 5 [4]. DSR and Ad-hoc On-demand Distance Vector (AODV) routing are the most popular and most studied reactive routing protocols. Our choice is a practical one: despite of the fact that recently several multipath routing protocols have been proposed, simulation implementations of them are not available. Although at the time of writing the latest internet draft of DSR was version 9 [5], the only available implementation was based on version 5 [4].

We have modified the implementation of DSR of NIST [2] to give support to multipath routing. The modifications are summarized below:

1. In DSR, although the route cache may contain several routes to the same destination, only the first route is used. In the modified version, packets are routed according to their flow identifier. Packets with flow id equal to 1 use the first route in the cache, packets with flow id equal to 2 use the second route in the cache, and so forth. If no route to the destination is found in the route cache, the packet is inserted in the send queue and the source node initiates a Route Discovery (if this has not been done yet).

2. As long as there is no route for the packets in the send queue, packets remain in the queue. In response to a route reply, packets are extracted from this queue. If the queuing delay of the packet is higher than a maximum predefined acceptable end-to-end delay (300 ms), the extracted packet is dropped. Otherwise, if there is a route available in the cache, the

packet is sent. If there is no route available in the cache, the packet is queued again.

3. Intermediate nodes that receive a route request, handle this request if they are not already in the route contained in the request packet (to avoid loops). The target of a route request packet may handle the same route request a predefined number of times, for example, the maximum number of descriptions used by any source. This ensures that more than one route reply can be sent by the target node in response to the same route request packet (to ensure that alternative routes are found).
4. Intermediate nodes are not allowed to send promiscuous replies.
5. Intermediate nodes are not allowed to shorten source routes contained in the packets they forward even when they know a shorter route, nor are they allowed to salvage packets.

The resulting protocol may be inefficient as many of the enhancements of DSR had to be modified or removed in order to support multipath routing. However, the goal of our study is not to develop a new multipath routing protocol.

3.5 Performance Metric

We are interested in the following performance metric. First, for each batch i, $i=0,1,2,\ldots$ we define the *quality* Q_i. The quality of a batch is a real number between zero and unity and depends on the number of packets of the batch that were received correctly (i.e., without transmission errors) and timely (within a fixed interval, the maximum end-to-end delay, after the packet is sent by the source node) at the destination node.

When in case of a number F of descriptions, a number of $q(i)$ of packets of batch i are received correctly and timely, the quality of the batch is defined by

$$Q_i = 1 - 2^{-q(i)}, \qquad q(i) = 0,1,\ldots,F-1,$$

$$Q_i = 1, \qquad q(i) = F.$$

The main idea behind this definition of the batch quality is that with MDC, receiving a single description already yields an acceptable quality (i.e., 50%). Receiving additional descriptions improves the quality, but the marginal gain decreases. The performance metric in which we are interested is the *expected stationary batch quality* $\mathbf{E}[Q]$, which we call the *stream success*.

4. SIMULATION SETUP

In Section 5 we will simulate our model in four scenarios. The simulation parameters common to all simulations are summarized in Table 1.

The WLAN data rate is the nominal capacity of the wireless network, and nodes have to be within 250 m from each other in order to communicate. Received packets with an end-to-end delay higher than 300 ms are considered lost. When using MDC, we only simulate two descriptions. As explained above, then the source produces twice as many packets, but the packets are only half the size (256 bytes instead of 512 bytes). The number of packets per description is 1876 and the per-description packet interarrival time is 0.032 seconds (except in Scenario 1). This amounts to a length of the simulated streams of one minute, and to a total transmission rate of 128 kbit/s (64 kbit/s for each description in case of two descriptions). Between two successive streams there are two minutes of no traffic.

Table 1. Common values of simulation parameters in all four scenarios. (The packet interarrival time per description is varied in Scenario 1.)

WLAN data rate	1 Mbit/s
Communications range	250 m
Maximum end-to-end delay	300 ms
Idle period between streams	120 s
Number of descriptions	1 or 2
Packet size	512 bytes (one description) 256 bytes (two descriptions)
Number of packets per description	1876
Packet interarrival time per description	0.032 s

5. SIMULATION RESULTS

For the simulation study, we chose a step-by-step approach, with four scenarios of increasing complexity. In Scenario 1, we consider a chain topology without multipath, with only one description, and without mobility, and we are interested in the transmission rate between the end points of the chain. In the other scenarios, we will assess the performance experienced by a single source-destination pair. In Scenario 2, we study the influence of mobility on multipath routing with MDC. In Scenarios 3 and 4, we have fixed topologies, and we introduce background traffic between another pair of nodes than the one under study, which will cause network congestion on one of the two routes. The simulated time is 10 minutes in Scenarios 1, 3, and 4, and 1 hour in Scenario 2. With the parameters as specified in Section 4, this amounts to 4 (or more in Scenario 1) and 20 replications, respectively, of a single stream in our simulations.

5.1 Scenario 1: Goodput in a Chain Topology

In Scenario 1, we have a number of nodes arranged in a chain topology, with a fixed distance between every two adjacent nodes of 180 m. So there is no mobility in this scenario, and only adjacent nodes are in each other's communications range. The source and destination nodes are the two nodes at the ends of the chain, and there is no other traffic in the system. In Figure 1 we show the topology with four nodes. Obviously, there is no use for MDC here, and the objective of the simulations is to obtain the maximum transmission rate that can be achieved between the end nodes of the chain for which the stream success is 100%. The number of nodes is varied between 2 and 6.

Figure 1. Scenario 1: a chain topology with four nodes.

As shown in Table 2, the higher the number of nodes, the lower the maximum transmission rate. This result will be used later to create congestion situations in certain parts of the network. Our results in Table 2 match those in [7] very well. There, it was found that with 1,500-byte packets (which exhibit similar performance to 500-byte packets) and a nominal WLAN capacity of 2 Mbit/s (which is twice our value), the maximal throughput in an 8-node chain is 0.25 times the maximum net available data throughput of 1.7 Mbit/s, or 0.425 Mbit/s. This is very close to twice our maximum transmission rate of 204 kbit/s for six nodes.

Table 2. Scenario 1: the maximum transmission rate with 100% stream success.

Number of nodes	2	3	4	5	6
Transmission rate (kbit/s)	650	328	215	210	204

5.2 Scenario 2: Effect of Mobility with a Random Topology

In Scenario 2, we have six nodes that move according to the Random Waypoint Model on a playfield of 400x400 m. The initial positions of the nodes are chosen at random and uniformly. The speeds of the nodes are varied between 0.5 and 1 m/s and between 1 and 4 m/s, to simulate slow walking and cycling, respectively. The positions of the nodes are recalculated every two seconds, and the pause time is constant at 10 seconds. The only traffic in the system is the communication between a single pair of nodes. The objective of these simulations is to assess the effect of mobility on the stream success when the source uses either one or two descriptions.

The average and the 90% confidence interval (CI) of the stream success for the case of two descriptions are shown in Table 3. We conclude that when two descriptions are used, on average, at any given point in time, at least one packet of either of the descriptions is received (and in time). With the speeds used in these simulations, the availability of routes will not change very often during the transmission of one stream (1 minute). As the nodes do move quite a distance in the simulated time of 1 hour with both speed ranges, we are in fact averaging over 20 streams with each a random initial position. Except for the overhead of finding new routes when routes break, it could be expected that the results for the different speed ranges are close. We conclude that in this scenario (the network is relatively dense and the network load is relatively low), mobility does not influence much the performance in terms of stream success.

Table 3. Scenario 2: the stream success with two descriptions.

Min. speed (m/s)	**Max. speed (m/s)**	**Average stream success (%)**	**Stream success 90% CI**
0.5	1	73	(58.95, 87.04)
1	4	71.25	(57.23, 85.27)

The results of the simulations when the source uses one description are summarized in Table 4. We conclude that in this scenario with mobility, the performance is better when one description is used than when two descriptions are used by the source.

Table 4. Scenario 2: the stream success with one description.

Min. speed (m/s)	**Max. speed (m/s)**	**Average stream success (%)**	**Stream success 90% CI**
0.5	1	91.95	(82.47, 101.43)
1	4	87.29	(76.09, 98.49)

5.3 Scenario 3: Two Node-disjoint Paths and Background Traffic I

In Scenario 3 (see Figure 2 for the topology used) we have two node-disjoint paths between the pair of nodes under study. In addition, we introduce background traffic in the form of communication between two adjacent nodes along one of these paths. There is no mobility.

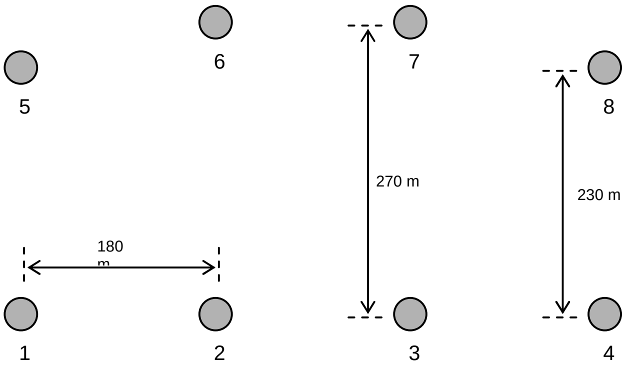

Figure 2. Scenario 3: eight nodes and two node-disjoint paths.

The communicating pair under study consists of node 1 as the source and node 4 as the destination, and the node-disjoint paths which are actually found by our modified version of DSR are 1-2-3-4 and 1-5-6-7-8-4. Communication from node 3 to node 2 is added as background traffic. The distance between nodes 2 and 5, and between nodes 3 and 8, is larger than 250 m. As a consequence, node 5 (8) is not in the communications range of node 2 (3), what makes this scenario attractive from the interference point of view. It should be noted that in other scenarios in which multiple routes exist, the routing protocol (a modified version of DSR) cannot select routes that fulfill this criterion. Therefore, the path choices in such cases can be less advantageous in terms of interference.

The objective of the simulations of this scenario is to determine whether increasing the number of descriptions, which is possible as two node-disjoint paths exist, can give a performance improvement when not all the traffic is received at node 4 due to the congestion caused by the background traffic from node 3 to node 2. Note that in this simulation, this background traffic is only started after the route discovery process initiated by node 1 is completed. When node 1 transmits with one description, all traffic follows the route 1-2-3-4. When it transmits with two descriptions, packets of the first description follow the same route and packets of the second description follow the route 1-5-6-7-8-4. The background traffic has a continuous transmission rate that varies between simulations: 128, 256, 384 and 512 kbit/s. The results of the simulations are shown in Figure 3.

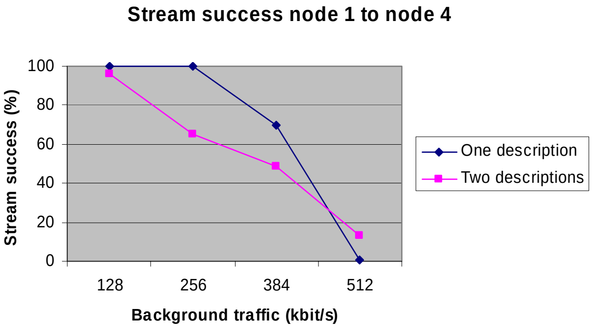

Figure 3. Scenario 3: the stream success versus the background traffic.

It cannot be concluded that in terms of stream success using two descriptions is better than using one description. The use of two descriptions is only better when the background traffic is 512 kbit/s. In that case, route 1-2-3-4 cannot support 128 + 512 kbit/s (which is over the throughput limit as shown in Table 2), whereas using an alternative route allows some packets to be received. However, the number of timely received packets is then very low and so is the stream success (13%).

With a background traffic of 256 kbit/s, while all packets are received and in time when node 1 uses one description, when it uses two descriptions, the stream success is much lower (65%). This has to do with the enormous delays experienced by some of the packets at the MAC layer due to retransmissions. For some packets, many retransmission attempts are made before the packet is successfully received. This occurs mainly at nodes 1, 2, 3, and 8. For example, with one description, node 4 “hears” the transmissions of node 3 to node 2 and the transmissions of node 3 to itself. With two descriptions, node 4 hears the transmissions of node 3 to node 2, and the transmissions of nodes 3 and 8 to itself. The use of the second route does not improve the results because this route is also influenced by the background traffic. For example, node 4 cannot acknowledge packets coming from node 8 when node 3 is sending to node 2.

In case of a background traffic of 128 kbit/s, when two descriptions are used, the number of packets that have to be retransmitted many times is low (only a few packets experience long delays). This is why the stream success is 96%. When one description is used, almost no packet has to be retransmitted. All packets are received in time and therefore, the stream success is 100%.

5.4 Scenario 4: Two Node-disjoint Paths and Background Traffic II

Similarly as in Scenario 3, in Scenario 4 we have two node-disjoint paths between the pair of communicating nodes under study, and we have background traffic between two adjacent nodes in one of these paths. The scenario in the simulations is illustrated in Figure 4.

In this scenario, node 1 is the source and node 4 is the destination of the communication pair under study, but compared to Scenario 3, we have added two nodes on both paths between nodes 1 and 4. The two paths, which are actually found by our modified version of DSR, are now 1-9-2-3-10-4 and 1-5-11-6-7-12-8-4. The background traffic consists of node 3 sending to node 2. Similarly as in Scenario 3, the distance between nodes 5 and 9 and between nodes 8 and 10 is longer than 250 m. However, in contrast to Scenario 3, the distance between nodes 3 and 4 is longer than 250 m, and therefore, the background traffic does not directly affect node 4. It should again be noted that in general, the routing protocol (a modified version of DSR) can by no means find routes which meet this criterion (two node-disjoint paths in which all but the common nodes of the two routes are not in each other’s range and in which the common nodes are not in the range of other traffic sources) when other possible routes exist.

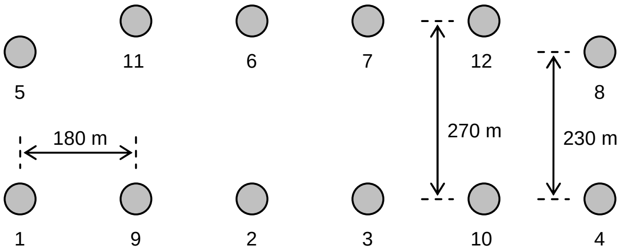

Figure 4. Scenario 4: twelve nodes and two node-disjoint paths.

The objective of the simulation is again to determine whether increasing the number of descriptions can give a performance improvement when not all the traffic is received at node 4 due to congestion caused by the background traffic from node 3 to node 2. Also in this simulation, the background traffic is only started after the route discovery process initiated by node 1 is completed. When node 1 transmits with one description, all traffic follows the route 1-9-2-3-10-4. When it transmits with two descriptions, packets of the first description follow the same route, and packets of the second description follow route 1-5-11-6-7-12-8-4. Again, while the source under study, node 1, always transmits at 128 kbit/s to node 4, the background traffic varies between simulations: 128, 256, 384 and 512 kbit/s.

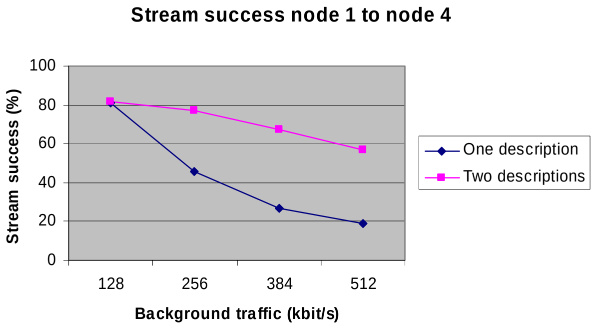

Figure 5. Scenario 4: the stream success versus the background traffic.

As shown in Figure 5, the performance in terms of stream success is in all cases better when the source sends with two descriptions instead of one. The performance difference is more significant when the background traffic increases. For example, for a background traffic of 256 kbit/s, whereas with one description the stream success is 46% (this can be interpreted as just one packet received for every two packets sent), with two descriptions, the stream success is 77% (for every two packets sent, half of the time both are received and half of the time, one is received). Therefore, by carefully choosing the second route, it can be guaranteed that using two descriptions gives a performance improvement over using one path and one description. However, as mentioned before, no existing routing protocol can deliberately make such route choices (routes with characteristics similar to those in Figure 4) when other possible routes exist.

6. CONCLUSIONS

In this paper we have compared the performance of multipath routing combined with multiple description coding with single-path routing and single-description coding in ad-hoc networks. In our scenario with mobility, the performance of multipath routing is worse than the performance of single-path routing. In scenarios where the use of multiple descriptions is aimed at relieving certain parts of the network where congestion occurs, multiple description coding gives a better performance only in very specific scenarios, where the routes chosen satisfy very specific requirements (node-disjoint routes in which the alternative route is not affected by the congestion). Current routing protocols are just not able to choose routes with such characteristics.

Our main result is that multipath routing may not be the best way to improve the performance of current and near future ad-hoc networks, as long as these networks are based on IEEE 802.11 as we know it today and the routing protocols are the ones we know today. However, we do admit that this paper only provides some initial insights by considering a limited set of scenarios, and that much more extensive research is needed to draw definitive conclusions. Other future research can be oriented to obtain experimental results to contrast our simulation results or to study solutions at the physical layer that help to reduce the interference problems that we have pointed out in this work.

7. ACKNOWLEDGMENTS

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