NB-TRACE: Network-Wide Broadcasting Through Time Reservation Using Adaptive Control For Energy Efficiency

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Abstract- In this paper, we present Network-wide Broadcasting through Time Reservation using Adaptive Control for Energy efficiency (NB-TRACE), which is an energy-efficient network-wide voice broadcasting architecture for mobile ad hoc networks. In the NB-TRACE architecture, the network is organized into overlapping clusters, where the clusterheads create a non-connected dominating set. Channel access is regulated through a locally maintained distributed TDMA scheme. The first group of packets of a broadcast session is broadcasted through blind flooding. Each data rebroadcast includes an implicit acknowledgement to the upstream node. Nodes that do not get acknowledgement for a predetermined time, except the clusterheads, cease to rebroadcast, which prunes the redundant retransmissions. The distributed connected dominating set formed through this basic algorithm is broken in time due to node mobility. The network responds to the broken links through passive and active clusterhead data transmission monitoring to ensure the maintenance of the connected dominating set. We compare NB-TRACE with flooding and gossiping using the MH-TRACE, IEEE 802.11, and SMAC medium access control protocols through ns-2 simulations. Our results show that NB-TRACE outperforms other network/MAC layer combinations in terms of energy efficiency, packet delivery ratio, jitter, and number of rebroadcasts.

I. INTRODUCTION

A. Motivation

One of the most important functions of a mobile ad-hoc radio network in many applications is to create a platform for voice communications. Occasionally, voice data need to be broadcast throughout the entire network. However, due to the limited radio range, system configuration, metal barriers, and interference, direct broadcast to all the nodes in the network using single hop broadcasting is not possible in many ad hoc network scenarios, and thus multi-hop broadcasting is unavoidable. Although multi-hop broadcasting is employed primarily as an auxiliary network service (*e.g.,* for route discovery), it can also be used as a standalone service, especially for voice communications. For example, a commander in an army unit may need to communicate with all members of the unit connected to the network, or the leader of a field trip may want to provide instructions to all group members present.

In network-wide voice broadcasting, we have three main criteria to evaluate the performance of the network architecture: application Quality of Service (QoS), energy efficiency, and efficient bandwidth utilization. QoS for voice communications requires that (i) the maximum packet delay is kept within specific bounds (*i.e.,* if end-to-end delay exceeds certain bounds, then the interactivity of the voice communication deteriorates), (ii) jitter is low, and (iii) the packet delivery ratio is high. Energy efficiency is crucial because mobile nodes are equipped with short-range lightweight radios operating with limited energy. Avoiding energy waste for these radios is of the utmost importance in order to keep the nodes connected to the network.

B. QoS Bounds for Voice Traffic

QoS for streaming media throughout the network necessitates timely delivery of packets (bounded delay), low jitter, and high packet delivery ratio [1][2][3]. Packet delay is directly related with the number of hops traversed by the voice packets and the contention level of the network. In a highly congested network, the packets are backlogged in the Medium Access Control (MAC) layer before they can be transmitted, which increases the packet delay beyond the acceptable limits. To ease congestion, packets that have exceeded the delay bound can be dropped rather than transmitting them to the destination, as they are no longer useful to the application. However, excessive packet drops decrease the packet delivery ratio, which is the other important aspect of QoS for streaming media. Packet delivery ratio is also decreased by collisions. Thus, there are two mechanisms that negatively affect the packet delivery ratio: packet drops and collisions.

Jitter in packetized voice traffic can be defined as the deviation from the periodicity of packet receptions. For zero jitter, the inter-arrival time between voice packet receptions should be identical and equal to the packet generation period, T_{PG}. One way to achieve good jitter performance is to reserve bandwidth between the source and destination(s).

In broadcasting scenarios, where acknowledged data delivery is not practical, QoS of the streaming media is determined primarily by the MAC layer. One solution to meet the delay, jitter, and packet delivery requirements for voice is to use periodic time-frame based medium access with automatic renewal of channel access, where the frame rate is matched to the periodic rate of the voice sources [4].

C. Energy Dissipation

Avoiding energy waste is crucial in order to keep the nodes connected to the network. Energy efficiency can be achieved by (i) optimizing the transmit power, which is proportional to the transmit range, (ii) minimizing the idle energy dissipation, which means maximizing the sleep time, (iii) avoiding overhearing irrelevant packets, (iv) avoiding unnecessary carrier sensing, (v) reducing the overhead (*i.e.,* bandwidth and energy used for anything other than optimal data transmission and reception) as much as possible without sacrificing the robustness and fault tolerance of the network, and (vi) reducing the number of retransmissions in broadcasting scenarios as much as possible.

By considering both transmit and receive energy dissipation, it has been shown that for a given energy and propagation model there is an optimum transmit radius, D_{OP}, beyond which single hop transmission is less energy efficient than multi-hop transmissions [5].

Avoiding energy dissipation in the idle mode (idle and carrier sense energy) necessitates coordination through scheduling between the nodes, so that nodes avoid idle listening or overhearing irrelevant packets or collisions [6][7][8], especially in broadcasting scenarios. While this goal can be accomplished using centralized control, this is not practical in a mobile ad hoc network, or at least not scalable due to the high overhead to monitor and convey the control information throughout the network.

To avoid wasting energy in idle mode, nodes should be kept in sleep mode. SMAC [8] is an energy efficient MAC protocol, which saves energy by periodically switching between the sleep and awake modes, where the total sleep/awake ratio, R_{SA}, and sleep/awake cycle, T_{SA}, are fixed.

Especially in broadcasting, many redundant versions of the same packet are received by each node, which results in receive energy dissipation for no gain. An efficient solution to this problem is information summarization prior to data transmission through a short information summarization (IS) packet that includes metadata summarizing the corresponding data packet transmission [9] (*i.e.,* data packet ID can be the metadata included in the IS packet in voice broadcasting). A node that has already received a packet will be prevented from receiving redundant copies of the same packet, which are identified through corresponding IS packets, by entering the sleep mode.

D. Efficient Bandwidth Utilization

In broadcasting the efficiency of bandwidth utilization is measured by the number of retransmissions required for a packet to be received by all the nodes in the network [10]. Many algorithms have been proposed for network-wide broadcasting, and they can be classified into three main categories: (i) non-coordinated, (ii) fully coordinated, and (iii) partially coordinated. Flooding is an example of a non-coordinated broadcast algorithm, where nodes rebroadcast without any coordination [11]. However, in order to avoid excessive collisions, nodes retransmit with a random broadcast jitter, which is uniformly distributed in [0, T_{BJ}]. Gossiping is another example of a stateless (non-coordinated) broadcast algorithm [12], where nodes rebroadcast with a predetermined probability p_{GSP} in conjunction with the broadcast jitter. The goal of a fully coordinated algorithm is to create a Minimum Connected Dominating Set (MCDS), which is the smallest set of rebroadcasting nodes such that the set of nodes are connected and all non-set nodes are within transmit range of at least one member of the MCDS [10]. However, creation of an MCDS is not practical, even with the assumption of global knowledge, due to the NP-hardness of the problem. Partially coordinated broadcast algorithms can be considered as approximate limited scope MCDS's based on one-hop or two-hop neighborhood and/or topology information [10]. The efficiency of these algorithms is better than non-coordinated algorithms and they do not need global information, unlike fully coordinated algorithms.

Although all of the major components of energy-efficient QoS-supporting network-wide broadcasting have been investigated extensively in the literature, a multi-objective architecture that integrates all of the design goals has not been proposed to the best of our knowledge. In this paper we propose such a network architecture, called Network-wide Broadcasting through Time Reservation using Adaptive Control for Energy Efficiency (NB-TRACE).

The remainder of this paper is organized as follows. Section II describes the NB-TRACE architecture. The simulation environment and results are presented in Section III. Conclusions are drawn and future work is addressed in Section IV.

II. PROTOCOL ARCHITECTURE

NB-TRACE is a network architecture designed for energy-efficient voice broadcasting. NB-TRACE is created though the integration of network layer network-wide broadcasting with the MH-TRACE (Multi-Hop Time Reservation using Adaptive Control for Energy efficiency) MAC protocol [9]; thus, NB-TRACE is a cross-layer architecture.

In NB-TRACE, the network is organized into overlapping clusters, each managed by a clusterhead (CH). Channel access is granted by the CHs through a dynamic, distributed Time Division Multiple Access (TDMA) scheme, which is organized into periodic superframes. Initial channel access is though contention, however, a node that utilizes the granted channel access automatically reserves a data slot in the subsequent superframes. The superframe length, T_{SF}, is matched to the periodic rate of voice generation.

Data packets are broadcasted to the entire network though flooding at the beginning of each voice session. Each rebroadcasting (relay) node implicitly acknowledges the upstream node as part of its data transmission. Relay nodes that do not receive any acknowledgement in T_{ACK} time cease to rebroadcast. As an exception, the CHs continue to rebroadcast regardless of any acknowledgement, which prevents the recursive and eventual collapse of the broadcast tree.

Due to node mobility, the initial tree will be broken in time. To maintain the broadcast tree, NB-TRACE is equipped with several mechanisms: (i) Relay Status Reset (RSR), (ii) CH Rebroadcast Status Monitoring (RSM), and (iii) Search for Data (SD). In the following subsections, detailed descriptions of MH-TRACE and NB-TRACE will be presented.

A. MH-TRACE

Multi-Hop Time Reservation Using Adaptive Control for Energy Efficiency (MH-TRACE) is a MAC protocol that combines advantageous features of fully centralized and fully distributed networks for energy-efficient real-time data broadcasting [13]. Figure 1 shows a snapshot of MH-TRACE clustering and medium access for a portion of a distribution of mobile nodes. In MH-TRACE, the network is partitioned into overlapping clusters through a distributed algorithm. Time is organized into cyclic constant duration superframes consisting of several frames. Each CH chooses the least noisy frame to operate within and dynamically changes its frame according to the interference level of the dynamic network. Nodes gain channel access through a dynamically updated and monitored transmission schedule created by the CHs, which eliminates packet collisions within the cluster. Collisions with the members of other clusters are also minimized by the CH's selection of the minimal interference frame.

Ordinary nodes are not static members of clusters, but they choose the cluster they want to join based on the spatial and temporal characteristics of the traffic, taking into account the proximity of the CHs and the availability of the data slots within the corresponding cluster. Each frame consists of a control sub-frame for transmission of control packets, and a contention-free data sub-frame for data transmission (see Figure 2). Beacon packets are used for the announcement of the start of a new frame; CH Announcement (CA) packets are used for reducing co-frame cluster interference; contention slots are used for initial channel access requests; the header packet is used for announcing the data transmission schedule for the current frame; and Information Summarization (IS) packets are used for announcing the upcoming data packets. IS packets are designed to be versatile, and they are crucial in energy saving. Each scheduled node transmits its data at the reserved data slot.

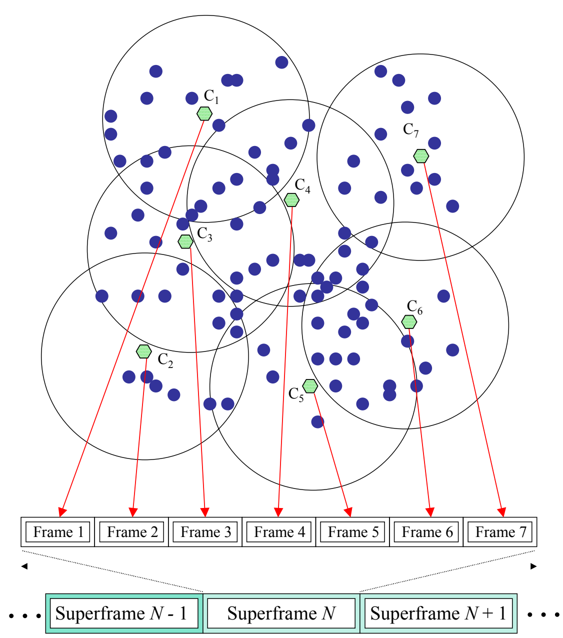

Figure 1. A snapshot of MH-TRACE clustering and medium access for a portion of an actual distribution of mobile nodes. Nodes C_1 - C_7 are CHs.

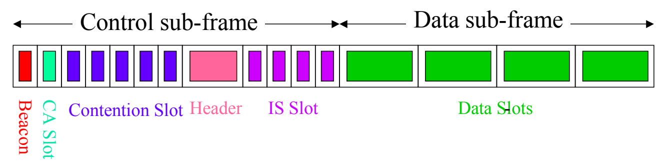

Figure 2. MH-TRACE frame structure.

Nodes that are scheduled to transmit data send a short information summarization (IS) packet prior to data transmission. The IS packet includes information about the data packet, where the content of the IS packets can be modified to fit the requirements of different applications. For example, in broadcasting, we include the source ID and the packet sequence number in the IS packet, so that nodes that already received a particular data packet avoid receiving a duplicate of the same packet, which saves a considerable amount of energy.

There are several mechanisms in MH-TRACE that provide energy efficiency: (i) nodes are in the sleep mode whenever they are not involved in data transmission or reception, which saves the energy that would be wasted in idle mode or in carrier sensing, and (ii) nodes can selectively choose what data to receive based on information from the IS packets, enabling the nodes to avoid receiving redundant data (*i.e.,* multiple receptions of the same packet).

Instead of frequency division or code division, MH-TRACE clusters use the same spreading code or frequency, and inter-cluster interference is avoided by using time division among the clusters to enable each node in the network to receive all the desired data packets in its receive range, not just those from nodes in the same cluster. Thus, the MH-TRACE clustering approach does not create hard clusters—the clusters themselves are only used for assigning time slots for nodes to transmit their data.

B. NB-TRACE

The basic design philosophy of NB-TRACE is to flood the network and, by using the properties of the underlying MH-TRACE architecture, to prune the network as much as possible while maintaining a connected dominating set with minimal control packet exchange (*i.e.,* minimizing the overhead). NB-TRACE is composed of five basic building blocks: (i) Initial Flooding (IF), (ii) Pruning, (iii) Relay Status Reset (RSR), (iv) CH Rebroadcast Status Monitoring (RSM), and (v) Search for Data (SD). The NB-TRACE algorithm flowchart is presented in Figure 3.

1) Initial Flooding: The source node initiates a session by broadcasting packets to its one-hop neighbors. Nodes that receive a data packet contend for channel access, and the ones that obtain channel access retransmit the data they received. Eventually, the data packets are received by all the nodes in the network, possibly multiple times.

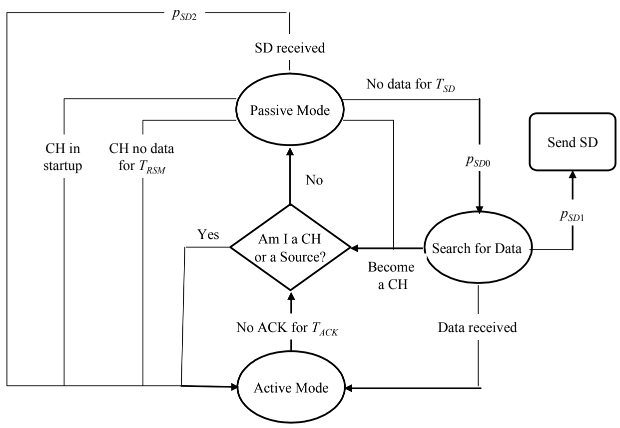

Figure 3. NB-TRACE flowchart.

2) Pruning: The rebroadcasting nodes include the ID of the upstream node from which they first received the corresponding data packet in their IS packets, which provides a virtual acknowledgement for the upstream node. The content of the IS packets of MH-TRACE is slightly modified in NB-TRACE. IS packets include the source node ID, upstream node ID, and packet ID. Relay nodes that do not receive an acknowledgement for T_{ACK} time cease rebroadcasting and return to passive mode. Nodes need to wait for T_{ACK} to cease relaying because network dynamics may temporarily be preventing a downstream node from acknowledging an upstream node (*e.g.,* mobility, cluster maintenance). Nodes in passive mode do not relay packets, they just receive them, and nodes in active mode keep relaying packets. However, this algorithm has a vital shortcoming, which leads to the silencing of all relays eventually. The outermost nodes will not receive any acknowledgements, thus they will cease relaying, which also means that they cease acknowledging the upstream nodes. As such, sequentially all nodes will cease relaying and acknowledging, which will limit the traffic to the source nodes only (*i.e.,* source nodes always transmit). To solve this problem, we introduced another feature to the algorithm, which is that the CHs always retransmit, regardless of any acknowledgement reception. Thus, the broadcast tree formed by initial flooding (IF) and pruning always ends at CHs. Note that the CHs create a dominating set. Thus, if we ensure that all the CHs relay broadcast packets, then the whole network is guaranteed to be completely covered.

The first two blocks of the algorithm are sufficient to create a broadcast tree for a static network. However, for a dynamic network we need extra blocks in the algorithm, because due to mobility the broadcast tree will be broken in time. The simplest solution would be to repeat the IF block periodically, so that the broken links will be repaired (actually recreated) periodically. Although this algorithm is simple, it would deteriorate the overall bandwidth efficiency of the network. The quest for more efficient compensation mechanisms lead us to design three maintenance procedures.

3) Relay Status Reset: One of the major effects of node mobility on NB-TRACE is the resignation of existing CHs and the appearance of new CHs. When two CHs enter each others' receive range, one of them resigns. If there are no CHs in the receive range of a node, it contents to become a CH. At the beginning of its operation as a CH, the CH stays in startup mode until it sends its header packet and announces its status with a bit included in the beacon packet. The appearance of a new CH generally is associated with the resignation of an existing CH. Whatever the actual situation, the nodes that receive a beacon packet from a CH in startup mode switch to active mode and rebroadcast the data packets they receive from their upstream neighbors until they cease to relay due to pruning. Although RSR significantly improves the system performance in combating node mobility, it cannot completely fix the broken tree problem. For example, a CH could just move away from its only upstream neighbor, which creates a broken tree. This problem (and other similar situations) cannot be handled by RSR. Thus, we introduce RSM, which, in conjunction with RSR, almost completely alleviates the tree breakage problem.

4) CH Rebroadcast Status Monitoring: One of basic principles of the NB-TRACE algorithm is that all the CHs should be rebroadcasting. If an ordinary node detects any of the CHs in its receive range is inactive for T_{RSM} time, then it switches to active mode and starts to rebroadcast data. As in the RSM case, redundant relays will be pruned in T_{ACK} time. In a network with high enough density to keep the network connected, the first four building blocks create an almost complete broadcasting algorithm capable of handling mobility. However, in some rare cases, some parts of the network could have lower density than the rest. An interesting situation arises in such low density network segments, which is illustrated in Figure 4. The two CHs (CH_1 and CH_2) are connected through two ordinary nodes (N_1 and N_2). Assume that CH_1 is connected to the rest of the network only through the distributed gateway formed by N_1 and N_2, and due to mobility or any other reason, the distributed gateway is not operational. None of the building blocks are capable of resolving this problem. Thus we devised the last building block, SD, to combat it.

5) Search for Data: An ordinary node which does not receive any data packets for T_{SD} time switches to SD mode with probability p_{SD0}, and sends an SD packet with probability p_{SD1}. The underlying MH-TRACE MAC does not have a structure that can be used for this purpose, thus we modified MH-TRACE to be able to send SD packets. SD packets are transmitted by using the IS slots through S-ALOHA, because all the nodes will be listening to the IS slots regardless of the energy saving mode. Upon reception of an SD packet, the

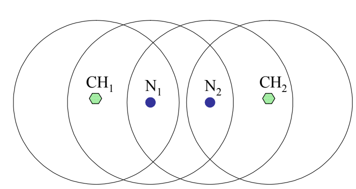

Figure 4. Illustration of the situation necessitating the SD block.

receiving nodes switch to active mode, and start to relay data with probability p_{SD2}. If the nodes that receive SD packets do not have data to send, they are either in SD mode or they will switch to SD mode. Upon receiving the first data packet, the nodes in SD mode will switch to active mode.

The probabilities p_{SD0}, p_{SD1}, and p_{SD2} are embedded into the SD block to avoid excessive SD packet transmissions. An adverse affect of the SD block is that the nodes will enter to SD mode in an inactive network, and they will transmit SD packets. Since SD packets are short, they will not be dissipating significant energy, and no bandwidth is wasted (*i.e.,* if there is at least one node scheduled to transmit in a frame then none of the nodes in SD mode will transmit SD packets in that frame).

III. SIMULATIONS

To test the performance of the NB-TRACE architecture and to compare it with other architectures, we ran simulations using the ns-2 simulator. We simulated conversational voice coded at 32 Kbps with 100-byte payload data packets, which corresponds to one voice packet per 25 ms. Data packet overhead is 10 bytes in all architectures. NB-TRACE control packets are 10 bytes, except the header packet, which is 22 bytes. All time slots are separated by one Inter-Frame Space (T_{IFS}) time, which is 16 µs. In NB-TRACE, there are 6 frames within the superframe. Each frame has 9 contention slots and 6 data slots. All the simulations are run for 1000 s. We used the energy and propagation models discussed in [14]. Voice packets exceeding the delay threshold, T_{drop}, are dropped in the MAC layer. Acronyms, descriptions and values of the parameters used in the simulations are presented in Table I.

We used the random way-point mobility model for nodes moving within a 1 km by 1 km area. Maximum node speed is set to 5.0 m/s (the average pace of a marathon runner). The pause time is set to zero to avoid non-moving nodes throughout the simulation time. There are 80 mobile nodes in our scenario and the static source node is located in the center of the network. This corresponds to a battlefield scenario where the soldiers are on foot (*i.e.,* pedestrian mobility) and the commander of the unit (*i.e.,* a squadron), communicates with the soldiers in the unit in broadcast fashion.

For comparison purposes we simulated Flooding and Gossiping as network layers, and 802.11 and SMAC as MAC layers. We optimized all of the schemes for the scenario that we considered.

QoS results for NB-TRACE are presented in Table II. To observe the effects of the various blocks of NB-TRACE, we ran simulations with several subsets of the five blocks. NB-TRACE 3B, NB-TRACE 4B, and NB-TRACE 5B use the first three, four, and five blocks, respectively. NB-TRACE 3B gives the least (average and minimum) packet delivery ratio (PDR), due mainly to the lack of block 4 (RSM). NB-TRACE 4B has the same average packet delivery ratio as the full NB-TRACE (NB-TRACE 5B). However, the minimum packet delivery ratio of NB-TRACE 4B is slightly lower than full NB-TRACE, which is due to the rarely occurring inactive distributed gateway situation.

Table I. Simulation parameters.

Acronym	Description	Value
N_N	Number of nodes	81
D_{TR}	Transmit range	250 m
D_{CS}	CS range	507 m
T_{drop}	Pck. drop thresh.	150 ms
P_T	Transmit power	0.60 W
P_R	Receive power	0.30 W
P_I	Idle power	0.10 W
P_S	Sleep power	0.01 W
C	Channel rate	2 Mbps
S	Source rate	32 Kbps
T_{PG}	Packer generation period	25 ms
N/A	Data packet payload	100 bytes
N/A	Data packet overhead	10 bytes
N/A	Control Packet size	10 bytes
N/A	Header packet size	22 bytes
T_{IFS}	Inter-frame space	16 µs
T_{SF}	Superframe time	25 ms
T_{ACK}	Data ACK time	$4T_{SF}$
T_{RSM}	RSM time	$5T_{SF}$
T_{DS}	DS time	$6T_{SF}$
p_{SD0}	1st SD probability	1
p_{SD1}	2nd SD probability	0.5.
p_{SD2}	3rd SD probability	1
T_{BJ}	Broadcast jitter	12.5 ms
p_{GSP}	Gossiping probability	0.6
T_{SA}	Sleep/awake cycle period	25 ms
R_{SA}	Sleep/awake ratio	0.25

NB-TRACE PDR is higher than the minimum requirement of voice traffic (95 %). Packet delay is much lower than the packet drop threshold (150 ms). RMS Jitter is also very low, which necessitates a jitter buffer of size one packet.

Table III gives a comparison of QoS metrics of NB-TRACE and other schemes. The highest average PDR is obtained with NB-TRACE and 802.11-based Gossiping. The minimum PDR of gossiping is lower than NB-TRACE and MH-TRACE-based Flooding due to the exponential decay of the rebroadcast probability. SMAC-based Gossiping has the lowest average and minimum PDR due to the reduction in the effective bandwidth (25 %).

Both NB-TRACE and flooding with MH-TRACE produced the minimum jitter, 2.0 ms, due to their reservation based structure. Although the jitter obtained with 802.11-based Gossiping is 46 % of NB-TRACE delay, jitter is three times as high as that of NB-TRACE.

The average number of rebroadcasts per Packet (ARP) for NB-TRACE, 18.6, is the lowest among all of the schemes. The second best is SMAC-based Gossiping, 43.8, due to its low PDR. The highest ARP, is obtained with 802.11-based Flooding, which is two times more than NB-TRACE ARP.

Table IV presents the energy dissipation values for all of the

Table II. NB-TRACE performance.

	P. Del. Ratio Avg. / Min.	RMS Jitter (ms)	Avg. Delay (ms)
NB-TRACE-3B	92 % / 72 %	2.0	30.0
NB-TRACE-4B	98 % / 96 %	2.0	30.0
NB-TRACE-5B	98 % / 97 %	2.0	30.0

Table III. General performance comparisons.

	Del. Ratio Avg / Min	RMS Jitter (ms)	Avg. Delay (ms)	ARP
NB-TRACE	98 % / 97 %	2.0	30.0	18.6
MH-TRACE (Flooding)	96 % / 95 %	2.0	31.0	53.4
802.11 (Flooding)	89 % / 89 %	13.0	28.0	72.5
802.11 (Gossip)	98 % / 94 %	6.0	14.0	48.3
SMAC (Flooding)	90 % / 81 %	27.0	94.0	71.0
SMAC (Gossip)	89 % / 81 %	24.0	81.0	43.8

broadcast schemes. NB-TRACE energy dissipation is the lowest, 43.1 mJ/s (per node average), which is followed by MH-TRACE-based Flooding (54.0 mJ/s). The highest energy dissipation is with 802.11-based flooding, 242.4 mJ/s. The largest energy dissipation term of NB-TRACE is in idle mode, which is dissipated mainly during the IS slots (*i.e.,* all nodes are always on during the IS slots). Due to the reduction in the number of retransmissions, NB-TRACE transmit energy dissipation is 38 % of that of MH-TRACE-based Flooding. SMAC-based Flooding and Gossiping energy dissipation is approximately 85 % of 802.11-based Flooding due to the energy savings in the sleep mode.

IV. CONCLUSION

In this paper we introduce NB-TRACE, an energy-efficient, QoS supporting, cross-layer architecture for voice broadcasting. Quantitative analysis through simulations show that NB-TRACE outperforms the broadcasting schemes that we considered in this study (MH-TRACE-based Flooding, 802.11-based Flooding and Gossiping, and SMAC-based Flooding and Gossiping) in terms of packet delivery ratio, jitter, average number of rebroadcasts per generated voice packet and energy dissipation. We have also shown that the sole function of NB-TRACE is to connect the Non-Connected Dominating Set (NCDS) formed by the CHs, maintained by the underlying MH-TRACE protocol. This mostly eliminates the burden of maintaining a CDS by the network layer (i.e., CHs, which forms the NCDS, are maintained by the MAC layer).

Table IV. Comparison of energy dissipation.

	Tot (mJ/s)	Trn (mJ/s)	Rcv (mJ/s)	CS (mJ/s)	Idl (mJ/s)	Slp (mJ/s)
NB-TRACE	43.1	3.1 / 7 %	9.2 / 21 %	8.6 / 20 %	14.4 / 33 %	7.9 / 19 %
MH-TRACE (Flooding)	54.0	8.1 / 15 %	13.1 / 24 %	13.7 / 25 %	11.3 / 21 %	7.9 / 15 %
802.11 (Flooding)	242.4	9.5 / 4 %	67.7 / 28 %	134.0 / 55 %	31.3 / 13 %	NA
802.11 (Gossip)	210.6	6.3 / 3 %	50.7 / 24 %	107.0 / 51 %	46.4 / 22 %	NA
SMAC (Flooding)	203.9	9.2 / 5 %	59.3 / 29 %	116.3 / 57 %	16.9 / 8 %	2.3 / 1 %
SMAC (Gossip)	203.3	8.1 / 4 %	59.3 / 30 %	116.7 / 57 %	16.9 / 8 %	2.3 / 1 %

Our future work will concentrate on extending the TRACE framework to multicasting and unicasting with multiple flows. In multicasting and unicasting, most of the building blocks of NB-TRACE need to be either modified or recreated. For example, it is not possible to depend on the CHs to avoid the collapse of the multicast tree due to pruning, because in multicasting not all of the CHs need to rebroadcast each multicast packet. Thus, a substantial modification in pruning is inevitable. Furthermore, neither RSM nor RSR blocks can be utilized as they are, and their functionality should be replaced by alternative mechanisms for multicasting and unicasting.

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