Comparison of Traditional and Opportunistic Multihop Routing in Wireless Networking Scalability

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***Abstract*—The effect of the network scalability on the performance of a wireless multihop network is investigated. A discrete event simulator is applied to examine the performance of the network with two classes of routing protocols: traditional vs. opportunistic. It is shown that the opportunistic routing can better utilize network redundancies, as compared to an upper bound of traditional routing based on global route optimization.**

I. INTRODUCTION

Multihop wireless communications can have important applications in large-scale wireless networks, where the source and destination nodes do not have to be in the direct communication range of each other, where relay nodes in-between the source and destination can relay wireless packets in multiple hops. As such, the coverage of the wireless network can be extended without cabling. Therefore, the scalability of a multihop wireless networks has two folds of meaning: 1) the end-to-end communication metrics over multiple wireless hops; 2) the same set of metrics when the network density increases.

Traditional multi-hop wireless networking requires a predetermined network topology where routing table can be set up and a predetermined spectrum allocation where point-to-point wireless links can be configured. Both requirements are meeting challenges in engineering practice. Spectrum availability is often volatile due to co-channel interference especially in unlicensed bands; and wireless node availability can be affected by traffic congestions and other factors such as battery and hardware failures. Therefore, in traditional wireless networking, it is often encountered that the communication throughput and latency performances can degrade fast (usually exponentially) with the number of wireless hops.

Large-scale cognitive wireless networking [1] has been proposed to tackle the above challenges by an integration of opportunistic routing and opportunistic spectrum access. Simulation studies[2, 3] have been conducted based on calibrated channel model to compare the performance of opportunistic and traditional routing in a multihop wireless networks, where opportunistic routing is shown to have multiple times higher throughput.

Opportunistic routing method was introduced in [4]. *Extremely Opportunistic Routing* (ExOR) has a slotted acknowledge mechanism in order to select the next relay node. If a node successfully received the data packet, it will then calculate the *expected transmission count metric*, which is a priority level and it based on the distance between the receiver and the destination node. *MAC-Independent Opportunistic Routing and Encoding Protocol* (MORE) tries to avoid duplicate packets that might occur in ExOR with the introduction of the concept of innovative packets. In [5, 6] a *Geographic Random Forwarding* (GeRaF) technique was proposed. Each packet carries the location of the sender and the destination, so that the prioritization of the candidates nodes is based on location information. *Hybrid ARQ-Based Intercluster Geographic Relaying* (HARBINGER) [7] combines GeRaF with a hybrid automatic repeat request(ARQ). *Coding-Aware Opportunistic Routing Mechanism* (CORE) [8] is an integration of localized interflow network coding and opportunistic routing. By integrating localized network coding and opportunistic forwarding, CORE enables a packet holder to forward a packet to the next hop that leads to the most coding changes among its forwarder set.

In this paper, we further investigate how the performance of traditional and opportunistic routing varies when the network density increases. It is shown though simulations that opportunistic routing can take better advantage of network density in terms of realizing higher throughput and lower energy consumption.

The rest of this paper is organized as follows: the routing protocols are described in Section II, and performance analysis and simulation results are presented in Section III, followed by conclusions in Section IV.

II. ROUTING PROTOCOLS

In this section, the link reliability calculation is described, followed by a briefly description of *traditional routing protocol* and *opportunistic routing protocol*.

A. Link Reliability

Every node in the network knows its relative location and can transmit packets to all the neighbor nodes in its transmission range. Every packet transmission is subjected to the *Packet Error Rate (PER)* of the link between the transmitter and the receiver. If we use Binary phase-shift keying (BPSK) without channel coding, the $PER(i)$ for any link i between node s and node j can be written as [9],

$$PER(i) = 1 - \left(1 - Q\left(\sqrt{\frac{2P_t \cdot G(i)}{\sigma_n^2}}\right)\right)^{F_d}, \quad (1)$$

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where P_t is the transmission power, σ_n^2 is the noise power, F_d is the length of the data, $Q(x) = \frac{1}{\sqrt{\pi}} \cdot \int_{\frac{x}{\sqrt{2}}}^{\infty} e^{-t^2} dt$ and

$$G(i) = A \cdot D(s,j)^{-n}$$

where A is a constant and $D(s,j)$ is the distance between node s and node j.

B. Traditional Routing Protocol

In traditional routing protocol, the path toward the destination is the smallest path, in term of hops, consist of links with PER equal or smaller than a *reliability threshold,* T_{PER}.

There is an initialization phase in traditional routing. During that phase, the nodes in the network calculated the PER for all their neighbor nodes. When a node has a packet to transmit, it will try to transmit the packet to the neighbor node which is closer to the destination and the $PER(i)$ of the link i between the nodes is equal or smaller than the reliability threshold, $PER(i) \leq T_{PER}$. That neighbor node will become the next relay node.

When the initialization phase is over, every node in the network knows its next relay node and forward all the packet to that node. If the next relay node is busy the transmitter has to wait. After the DATA transmission, the transmitter will wait for an ACK packet for time:

$$T_{ACK} = DATA_{TRANS} + ACK_{TRANS} + 2 * PROP + SIFS \quad (2)$$

where $DATA_{TRANS}$ and ACK_{TRANS} is the DATA and ACK transmission delay, $PROP$ is the propagation delay and *Short Interframe Space* $(SIFS)$ is the small time interval between the data frame and its acknowledgment.

If there is no ACK after time T_{ACK}, the transmitter will send the DATA packet again.

In this way, the routing path between the source and the destination is the smallest path, in terms of hops required, constructed with links with PER equals or smaller to the reliability threshold.

This approach of traditional routing enhances the reliability of the network. The PER between the transmitting nodes is small and in each time slot, packets are transmitted between neighbor nodes.

Moreover, each packet transmission is scheduled in the best possible way in order to avoid collisions. The described traditional routing comes with ideal scheduling. The nodes avoid retransmission due to collision because of the use of a global scheduler that decides when a node will transmit the data. In that case the result can be an upper-bound for traditional routing protocols.

C. Opportunistic Routing Protocol

Opportunistic routing follows a similar approach to [2]. It uses four types of packets: Request To Send (RTS), Clear To Send (CTS), DATA and ACK. RTS/CTS are used during the handshake process between neighbor nodes while ACKs are used for verification of DATA delivery. All the packets transmissions are subjected to PER.

When a node s has a packet to transmit, it broadcasts a RTS packet and waits for time T_{RTS}, for a CTS packet from any neighbor node. T_{RTS} is equal to:

$$T_{RTS} = RTS_{TRANS} + CTS_{TRANS} + 2 * PROP + SIFS \quad (3)$$

where RTS_{TRANS} and CTS_{TRANS} is the RTS and CTS transmission delay, respectively.

If there is no CTS after time T_{RTS}, the node will broadcast again a RTS.

The node that will reply first with a CTS packet, it will become the next relay node and the transmitter will forward the DATA packet to that node and will wait for an ACK packet for time T_{ACK}, Equation 2. Any CTS packet that will come to the transmitter for that DATA packet after the first CTS, will be ignored from the transmitter. When the receiver successfully gets the DATA packet, it will reply with an ACK to the transmitter and then it will follow the same procedure to find the next relay node.

When a node j receives a RTS packet, it will wait for time $T_{Backoff}$ before replying with a CTS. $T_{Backoff}$ is equal to:

$$T_{Backoff} = \frac{C_0}{D_{s,d} - D_{j,d}} + SIFS, i \neq d \quad (4)$$

where $D(s,d)$ is the distance between the transmitter node s and the destination node d and C_0 is a constant.

$T_{Backoff}$ is inverse proportional to the difference $d(s,d) - d(j,d)$. The neighbor node that is closer to the destination will have the smallest $T_{Backoff}$ and will try to reply first with a CTS packet.

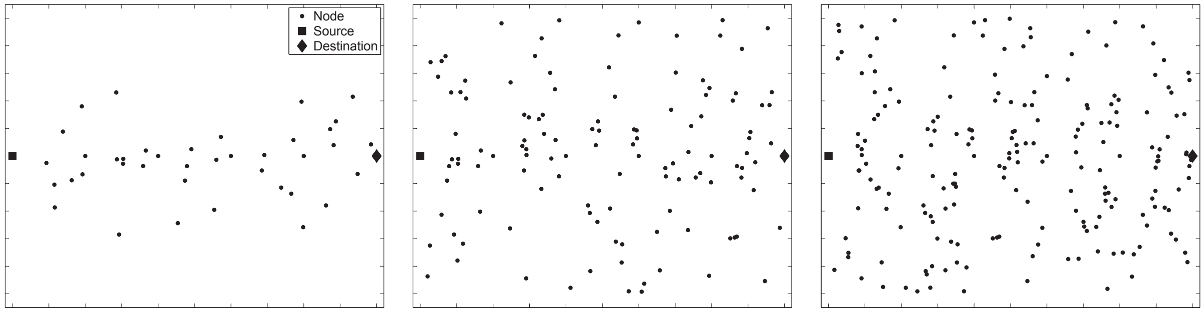
Following that approach, the next relay node will become the node which is closer to the destination and its link is available under the network conditions at every time slot.

Since every packet transmission is subjected to PER the routing path between the source and the destination changes dynamically. In every packet transmission the number of the successfully transmitted RTS and/or CTS packets is different, leading to different next relay nodes. Moreover, opportunistic routing tries to take advantage of the broadcast nature of wireless communications. In opportunistic routing the decision of the next relay node can change dynamically following link reliability in every time slot. Routing path is not predefined as in traditional routing. In this way, opportunistic routing is able to use any link that is available at a specific time slot, without the need of a *reliability threshold*.

III. PERFORMANCE ANALYSIS AND SIMULATION RESULTS

In this section, we will compare the network performance of traditional and opportunistic routing with respect to energy consumption and throughput and under different network density.

The network simulation was performed via the discrete event simulation system OMNeT++ [10]. The sensor nodes were uniformly randomly distributed over a $100 \times 100 (m^2)$ network field. The number of the nodes in the field were



(a) 40 nodes (b) 120 nodes (c) 200 nodes

Fig. 1: Network topology.

$40, 80, 120, 160$ and 200, leading to the 5 different network topologies. Figures 1(a) - 1(c) shows 3 of the topologies.

During the simulation, traditional route is identified by global optimization, and therefore is the best route available. A global scheduler is implemented during the initialization phase in order to avoid collisions. The results can be an upper-bound for traditional routing protocols.

Each node has a transmission range of 12 meters. The communication parameters were chosen based on IEEE 802.15.4, as listed in Table I. For traditional routing, the *reliability threshold* was set to $T_{PER} = 20\%$ while for opportunistic routing we also set up a *reliability threshold* at $T_{PER} = 80\%$.

Parameter	Unit	Value
F_d	*bit*	100×8
n		2.5
A	*dB*	-31
σ_n^2	dBm	-92

TABLE I: Communication Parameters Setup

Throughput: Throughput is the number of bits divided by the time needed to transport the bits. From the source node 100 packets were transmitted toward the destination. The simulation parameters can be are listed in Table II. For each network density, the simulation runs 10 times. The average throughput for each density can be seen in Figure 2.

Parameter	Unit	Value
$DATA\ packet$	*bit*	100×8
$RTS/CTS\ packet$	*bit*	8×8
$ACK\ packet$	*bit*	8×8
$SIFS$	μs	10

TABLE II: Simulation Parameters

In traditional routing, the next node selection is based on the link quality. Transmitter will forward the packets to the neighbor node that is closer to the destination and over the link that has a PER smaller than the *reliability threshold*. As the number of the nodes in the network is increased, there are more nodes between the source and the destination and the average number of neighbor nodes is increased. Hence, there are more nodes that are closer to the destination and have PER smaller than the reliability threshold. Traditional routing find those nodes during the initialization phase and create a new routing path. That path will have the same or smaller number of hops toward the destination and will lead to less packet losses due to the more reliable links that it will be using. As a result, the throughput is increased.

In opportunistic routing the next relay node change dynamically according to the network condition in each time slot. In a packet transmission, the next relay node is selected according to the link reliability at that time and node distance from the destination. Since the link reliability changes following the network conditions, opportunistic routing can discovery many different paths. Some of those path will require less hops, toward the destination, than traditional routing. Moreover, consequent packet transmissions can follow different paths. If a node is busy, the transmission process does not need to wait, as in traditional routing, till the node is available again. Other nodes can serve as relay nodes. In this way, the number of the packet that have been transmitted after a time t is higher than the number of the packets that have been transmitted in the same time in traditional routing. The throughput in opportunistic routing is always higher than traditional for the same network density.

As we increase the density, there are more paths toward the destination with less hops. Opportunistic routing tends to discover most of those paths, increasing the throughput. Furthermore, the average number of neighbor nodes is also increased, hence during a packet transmission, the transmitter will have a wider range of available next relay node to select. In every time slot, there will be a packet transmission, decreasing the total time spend in buffering the packets in the nodes and increasing the throughput.

Energy Consumption: Energy consumption is the total power that is needed from all the nodes in the network. From the source node 100 packets were transmitted toward the destination. Let the node power consumption in transmitting and receiving/idle modes be denoted by P_{trans} and P_r/i respectively. The sleeping mode power consumption is practically 1000 times smaller than P_{trans} and P_r/i, which is negligible. Let P_{trans} = 15mW and P_r/i = 10mW. For each network density, the simulation runs 10 times. The average energy for each density can be seen in Figure 3.

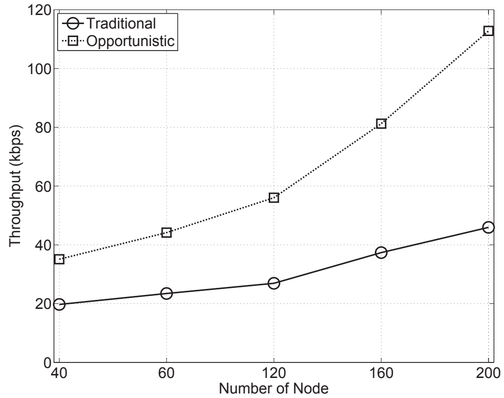


Fig. 2: Throughput under different number of nodes.

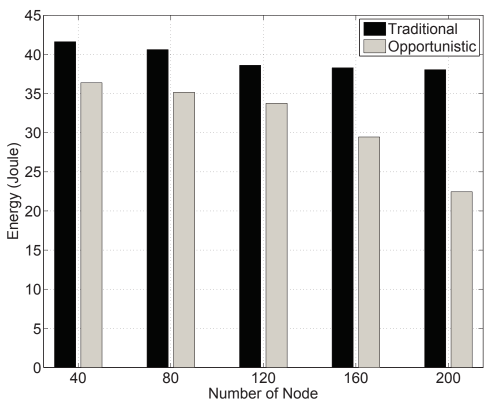


Fig. 3: Energy under different number of nodes.

Traditional routing will use the same nodes for every packet transmission. As the network density is increased, the hops required for a packet to reach the destination are decreased. The number of the nodes that are required for a packet transmission is decreased leading to a decrease in the network energy consumption. However, when one of the nodes in the predetermined path is busy, the total packet transmission will be delayed. The nodes will have to remain active longer, consuming more energy.

Opportunistic routing cope with that problem by using different nodes. As a result, in a specific network density, the nodes have to remain active for less time with opportunistic than with traditional routing. Moreover, as the density increased, more nodes can be served as next relay node while more paths with less hops can also be followed. In this way, the total energy consumption is decreased.

IV. Conclusion

The performance of traditional and opportunistic multihop routing is studied when network density increases. The network simulation results are obtained on end-to-end throughput and energy consumption of multihop wireless communications. It is shown that the opportunistic routing can better utilize network redundancies, as compared to an upper bound of traditional routing based on global route optimization.

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