Multi-Channel Opportunistic Routing in Multi-Hop Wireless Networks

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Introduction

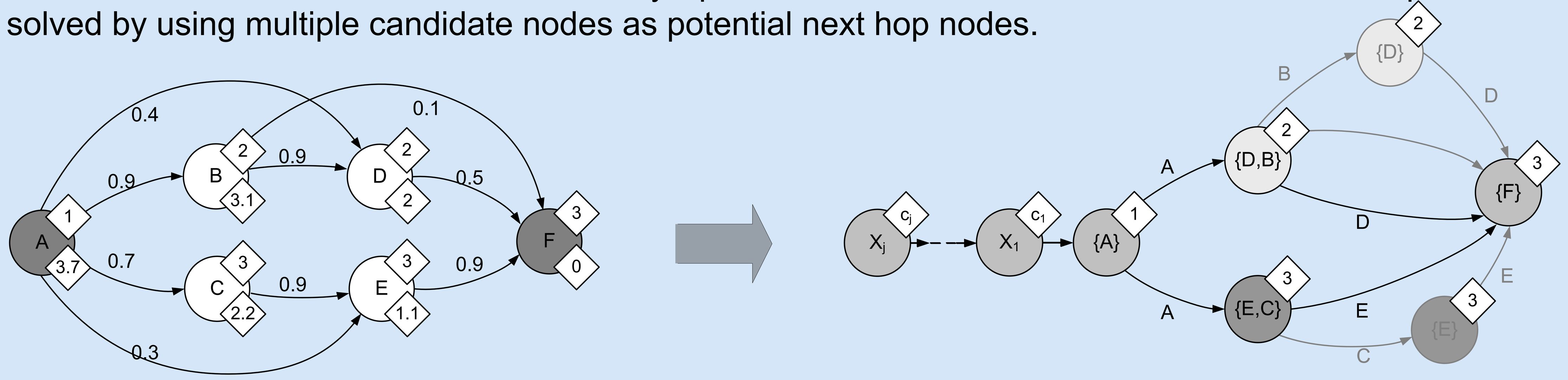
Wireless multi-hop mesh networks play an increasingly important role as backbones for sensor networks as well as community networks that provide Internet access in urban areas [1]. Nevertheless, one of their biggest challenges is the insufficient scalability with increasing number of nodes and users [2].

IEEE 802.11 provides several non overlapping RF channels. If multiple channels are used within one region multiple transmissions can take place simultaneously without interference. Most IEEE 802.11 devices are equipped with only one transceiver. This leads to the problem that nodes which operate on different channels cannot communicate with each other. Nevertheless, devices with just one transceiver can still make use of multiple channels by quickly switching to the channel of the intended receiver [3].

We propose and investigate Multi-Channel Extremely Opportunistic Routing (MCExOR) which is a protocol that extends ExOR [4] by utilizing multiple RF channels in multi-hop wireless networks. MCExOR reduces the overall number of transmissions in wireless multi-hop networks by opportunistically skipping nodes in a packet's forwarding path. The use of multiple non overlapping RF channels contributes to the reduction of overall interference.

Protocol Idea

Traditional routing protocols do not sufficiently consider the characteristics of the wireless medium [2]. In a wireless network we have lots of links with delivery probabilities different from one. The idea is to use them simultaneously as proposed by the ExOR protocol. In MCExOR the RF channel assignment is decoupled from the routing function - channels are assigned to nodes instead of flows. However, nodes operating on different channels create a new problem: 'deafness'. Deafness occurs if two nodes cannot communicate with each other because they operate on different channels. In MCExOR this problem is solved by using multiple candidate nodes as potential next hop nodes.



Network with link delivery probabilities shown along the edges; RF channels indicated by the number in the upper right corner and the expected transmission count to node F from each node of the graph indicated by the number in the lower right corner (left). In the associated candidate set graph the label on the edge between two candidate sets represents the particular forwarder (right).

Forwarding Algorithm

The main idea of MCExOR is to use a set of next hop candidates instead of only a single next hop:

Given a communication network *G=(V,E,f)*, vertex set *V={A₁,…,Aₙ}*, edge set $E \subseteq V \times V$, *f(e)* the link delivery probability of *e* ($e \in E$) *and g(x,y,z)* the expected transmission count of the path from node *x* over *y* to *z:*

$$g(x,y,z)=\sum_{e\in sp(x,y,z)}\frac{1}{f(e)}$$

sp(x,y,z) calculates the shortest path from node *x* followed by node *y* to *z*. A flow *c* is defined as $(u,v) \in V \times V$, where *u=source(c)* is the source of *c* and *v=sink(c)* is the sink of *c*. The algorithm *chooseCs(c,p,w,CSS)* calculates to a given packet p of flow *c*, a forwarding node *w* and a set of available candidate sets $CSS{:}P(V^n)$ the candidate set with the lowest metric towards the destination node *v=sink(c)*:

$$chooseCs(p,c,w,CSS)=cs, \quad \forall cs' \in CSS : csm(p,c,w,cs') \geq csm(p,c,w,cs)$$

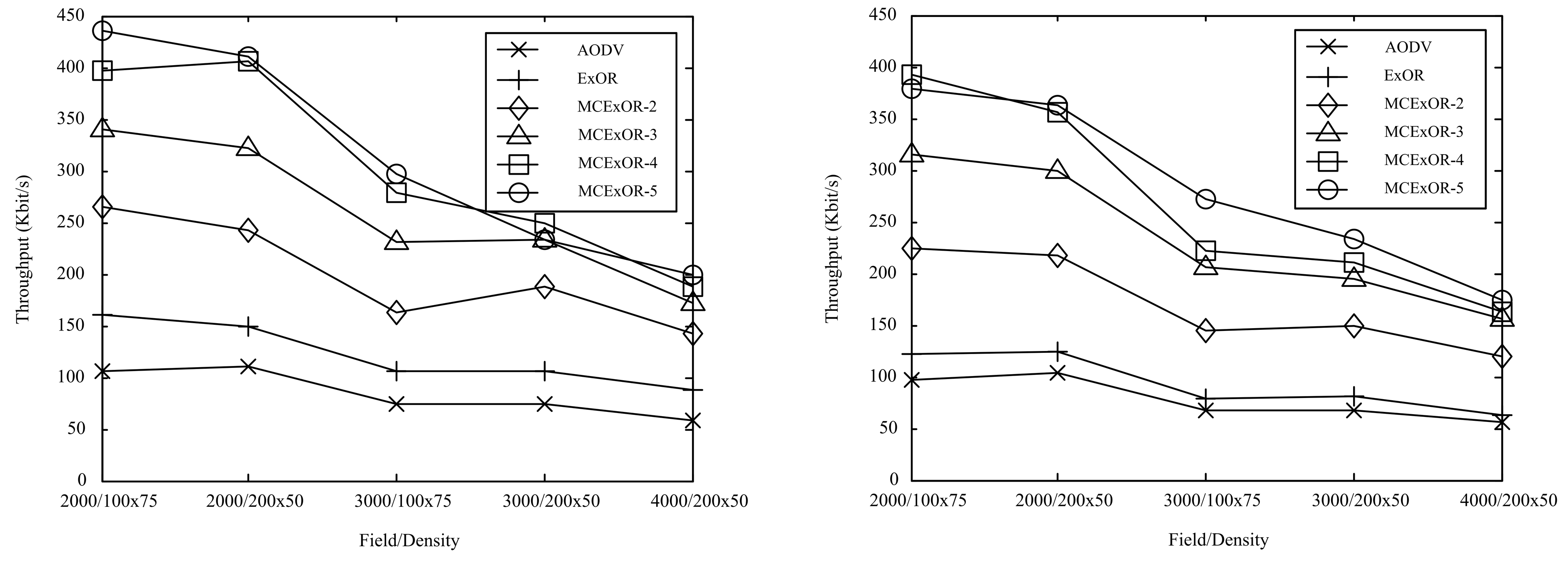
$$csm(p,c,w,cs=(c_1,\dots,c_n))=uch(p,ch(cs))\cdot\sum_{i=1}^{n} g(w,c_i,\mathrm{sink}(c))\frac{pcs(w,i,cs)}{1-pncs(w,i,cs)}$$

Whereas *csm(c,w,cs,p)* calculates the metric for each candidate set *cs* selected by a node *w* to a given packet *p* of flow *c*. *ch(cs)* represents the home channel of *cs*, whereas *uch(p,i)* calculates how often the packet *p* was transmitted on channel *i* plus one.

$$pncs(w,cs=(c_1,\dots,c_n))=\prod_{j=1}^{n}1-f(w,c_j) \qquad pcs(w,i,cs=(c_1,\dots,c_n))=f(w,c_i)\prod_{j=1}^{i-1}1-f(w,c_j)$$

Simulation Results

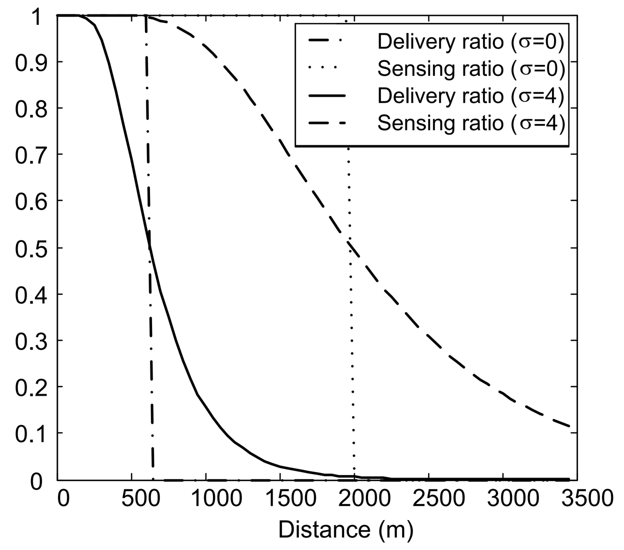
Simulation parameter	Value
Propagation model	Shadowing, Free Space
Path loss exponent β	2.0
Shadowing standard deviation σ	0..4 dB
Communication data rate	1 Mbit/s
Transmission strength	15 dBm
Radio reception sensitivity	-91 dBm
Radio reception threshold	-81 dBm
Radio RX/TX turnaround time	5 µs
Radio frequency	2.4 MHz
Signal to noise ratio	10
Radio channel switch turnaround time	80 µs
Slot time	20 µs
SIFS	10 µs
Retry limit	7
Collision window	31..1023



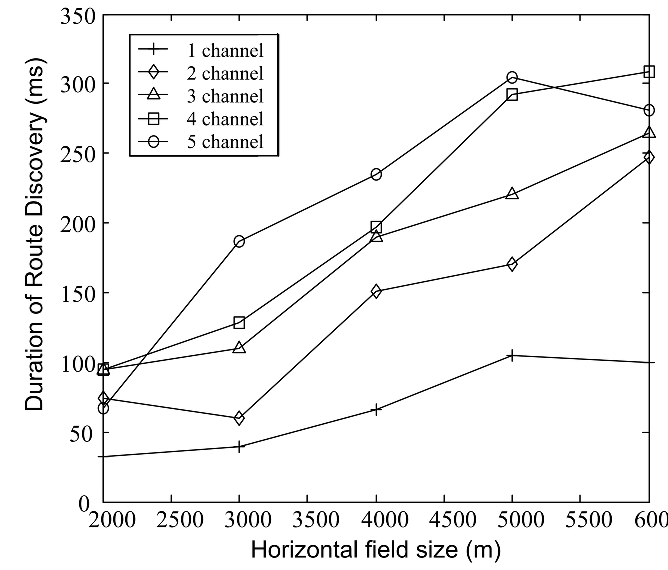
(a) 1 flow (b) 4 flows

AODV, ExOR and MCExOR with 2, 3, 4 and 5 RF channels with shadowing model.

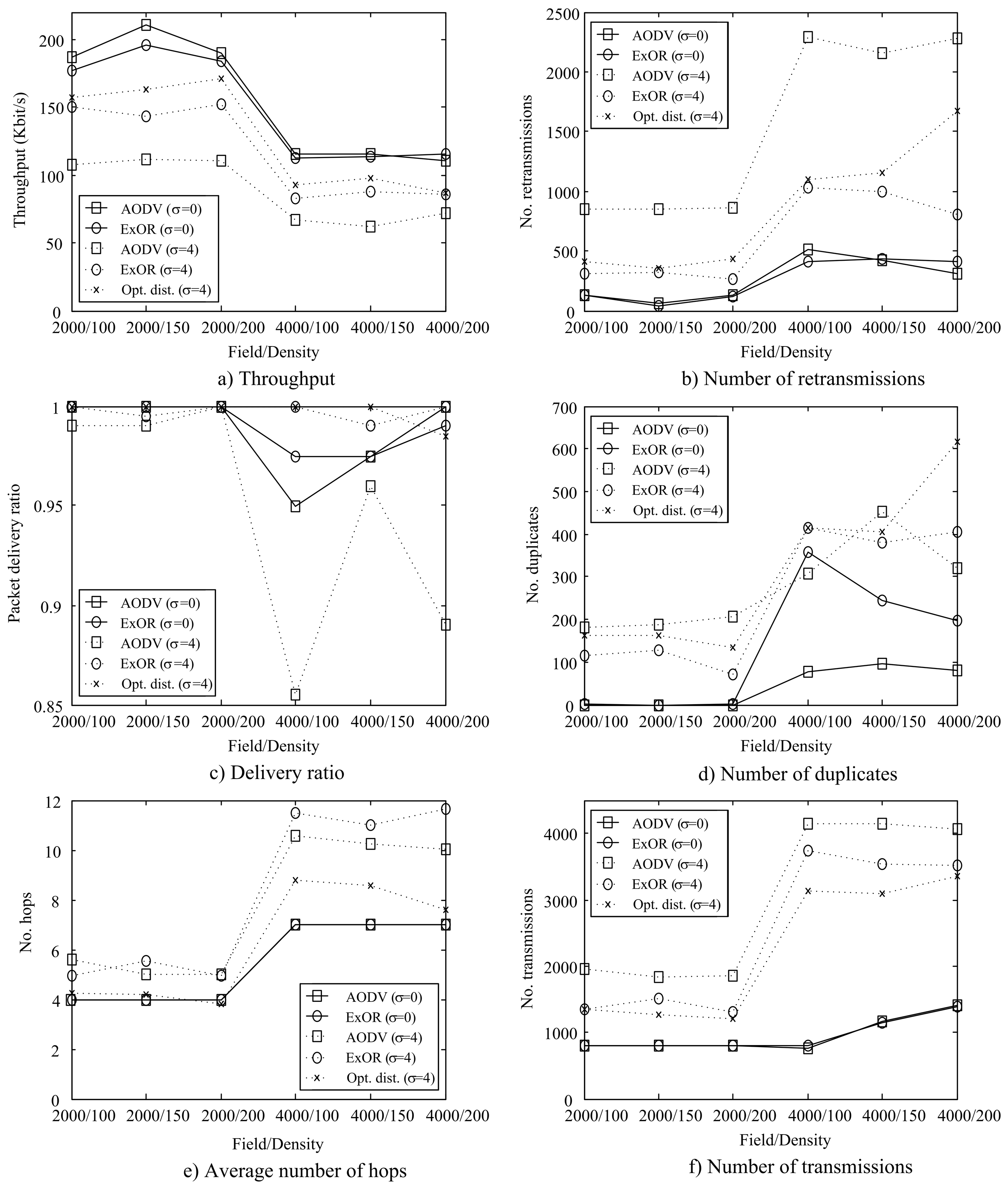
We implemented a prototype of MCExOR using the JiST/SWANS [5] wireless network simulator. Furthermore, we used the more realistic radio propagation model shadowing [6].



Delivery and sensing probability versus distance according to the free space and shadowing model.



Delay in the reactive route discovery due to the support of multiple channels.

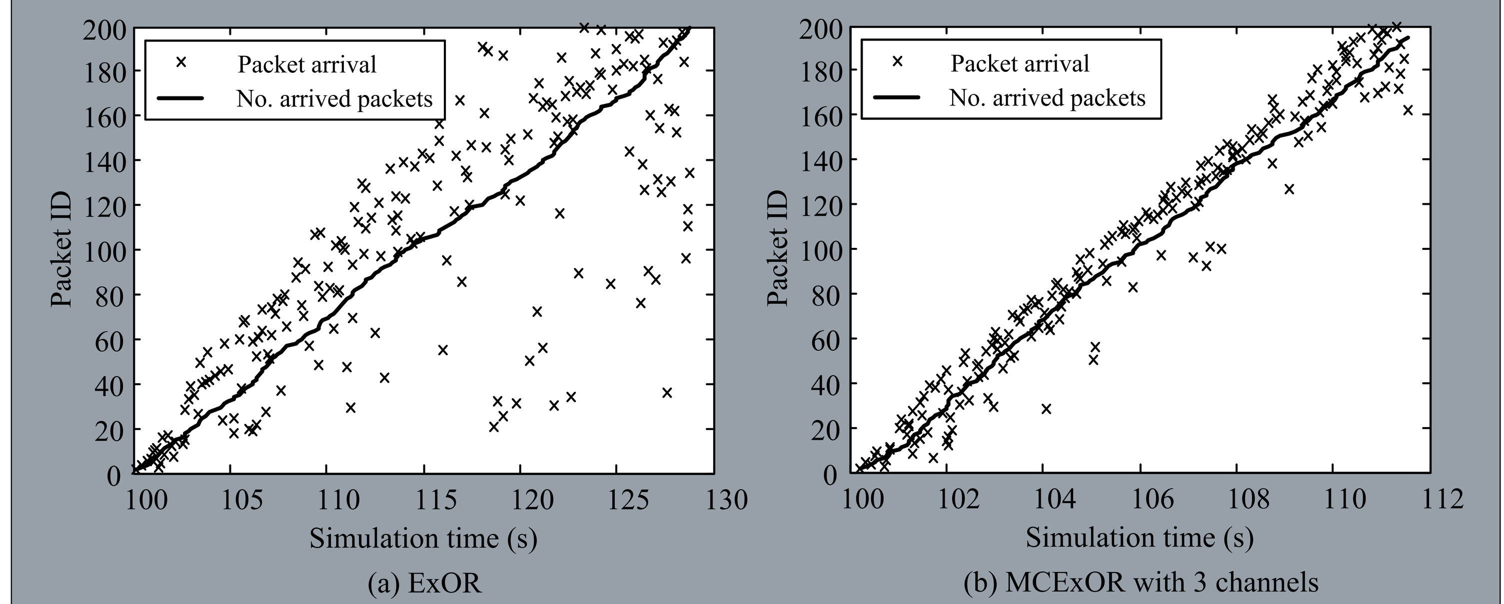


a) Throughput b) Number of retransmissions c) Delivery ratio d) Number of duplicates e) Average number of hops f) Number of transmissions

AODV vs. ExOR with Free Space (σ=0) and Shadowing Model (σ=4).

Future Work

In contrast to AODV, ExOR as well as MCExOR use multiple routing paths towards a destination. The ordering in which packets are sent is not necessarily the same in which they arrive. The problem of both protocols is packet reordering which leads to problems with TCP/IP. A task for the future is to make MCExOR more TCP-friendly and investigate its performance.



(a) ExOR (b) MCExOR with 3 channels

Packet arrival and number of arrived packets in relation to simulation time for ExOR (a) and MCExOR (b).

Conclusions

MCExOR enables devices with only one transceiver to operate on multiple RF channels. It minimizes the number of data transmissions and reduces interference to avoid packet collisions. Furthermore, MCExOR significantly outperforms traditional protocols like AODV due to its opportunistic feature. With the increasing number of RF channels the observed overall throughput superproportionally increases.

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[3] Richard Draves, Jitendra Padhye, and Brian Zill. Routing in multiradio multi-hop wireless mesh networks. ACM Mobicom, 2004.
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