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Energy-Constrained Wireless Devices BY MIMO

Kamlesh Hatewar

Abstract— *Leveraging the redundancy and parallelism from multiple RF chains, MIMO technology can easily scale wireless link capacity. However, the high power consumption and circuit area cost prevents MIMO from being adopted by energy constrained wireless devices. In this paper, we propose Halma, that can boost link capacity using multiple antennas but a single RF chain, thereby, consuming the same power as SISO. While modulating its normal data symbols, a Halma transmitter hops between multiple passive antennas on a per-symbol basis. The antenna hopping pattern implicitly carriers extra data, which the receiver can decode by extracting the index of the active antenna using its channel pattern as a signature. We design Halma by intercepting the antenna switching and channel estimation modules in modern wireless systems, including ZigBee and WiFi. Further, we design a modeldriven antenna hopping protocol to balance a tradeoff between link quality and dissimilarity of channel signatures. Remarkably, by leveraging the inherent packet structure in ZigBee, Halma's link capacity can scale well with the number of antennas. Using the WARP software radio, we have implemented Halma along with a ZigBee- and WiFi-based PHY layer. Our experiments demonstrate that Halma can improve ZigBee's throughput and energy efficiency by multiple folds under realistic network settings. For WiFi, it consumes similar power as SISO, but boosts throughput across a wide range of link conditions and modulation levels.*

Keyword *: RF, MIMO, SISO, WARP, ZigBee.*

INTRODUCTION

A MIMO has been a key enabling technology for recent high rate wireless standards. Compared with conventional SISO links, a MIMO transmitter can reduce bit-error-rate (BER) by redundantly coding the same data symbol through multiple antennas, thus achieving diversity gain. It also allows parallel transmission of different symbols through different antennas, thus achieving multiplexing gain. Both diversity and multiplexing mechanisms can scale throughput with the number of antennas without adding new spectrum. However, a MIMO radio must accompany each antenna with a separate RF chain. Most components in the RF chain build on analog technologies that hardly benefit from Moore's law. and remain fundamentally unchanged in the past two decades [1]. More critically, they account for the majority of the transceiver's power cost. Recent measurement studies revealed that MIMO power consumption increases linearly with the number of RF chains [2–4], which often nullifies the improvement in link capacity, resulting in even lower energy-per-bit than SISO. This is why most energy-constrained wireless devices, such as WiFi-equipped smartphones and ZigBee sensors, do not support MIMO.

Brief Literature Survey

Communication by switching antennas. Halma is partly inspired by the communication-theoretic concept of Space-Shift-Keying (SSK) [5, 21, 22], also referred to as Spatial Modulation (SMod) when augmented on top of narrowband PSK/QAM modulation mechanisms [23]. A solid theoretical foundation has been established that justifies the potential capacity gain of SMod over SISO (See [24] for a theoretical analysis, [6] for a comprehensive survey and [25] for a first measurement validation). We have thoroughly discussed Halma's unique advantages over conventional SSK (Sec. 1), particularly in its asymptotic gain in wide-band single-carrier and multi-carrier systems. To our knowledge, Halma is the first scheme that reveals these observations in a real implementation and unleashes the potential of antenna hopping for single RF-chain transceivers. Communication through side channels. Besides traditional modulation schemes, recent wireless networks witnessed many novel cross-layer communications schemes that exploit side channels. 802.11ec [26] employs short, correlatable symbol sequences to replace RTS/CTS, thus reducing the control message overhead. Flashback [13] embeds highpower single-tone signals into OFDM subcarriers, so as to create an extra control channel (with up to 400Kbps rate) on top of the normal data transmission. SideChannel [27] allows a transmitter to modulate energy pulses on top of an existing transmitter's packet, which can be identified by the receiver and improve ZigBee capacity by 2.5×. Both Flashback and SideChannel exploit the link margin between practical, conservative modulation protocols and an oracle choice. Similar to such schemes, the bonus bit-rate resulting from Halma's antenna index modulation can be applied to create a covert channel. Owing to multiple antennas, Halma's bonus channel demonstrats a much higher capacity. Antenna selection for MIMO networks. Halma's adaptive antenna hopping protocol inherits the insights from MIMO antenna selection. Information theoretic analysis has predicted the asymptotic SNR improvement from antenna selection to be log(Nt) times [28,29], assuming i.i.d. channel fading. Practical antenna selection protocols [18,30] tend to pick a single best antenna based on link quality estimation. In Halma, a transmitter adaptively picks a set of antenna to hop between, using a model-driven approach. Combined with antenna index modulation, it achieves much higher net- work throughput compared with traditional antenna selection schemes (Section 5). MIMO link energy optimization. Many MAC-layer protocols [3, 4, 10, 31] have been proposed that adaptively choose the number of RF chains to balance the throughput and energy consumption of WiFi MIMO transceivers. Halma sticks to a single RF-chain receiver, and consumes similar energy as SISO under real traffic patterns. Halma's link capacity can be further improved using multi-RF-chain receivers, which can exploit diversity to reduce antenna decoding error. Halma can even be integrated with MIMO spatial multiplexing, by allowing such receivers to simultaneously decode multiple streams of data, sent through different groups of transmit antennas. The throughput/energy tradeoffs in such mechanisms, and their integration with energyefficient MIMO MAC, will be left for our future exploration. Besides WiFi, we remark that Halma marks a first step in bringing multi-antenna benefits to ZigBee sensors without adding costly RF modules.

Research Methodology

Leveraging the redundancy and parallelism from multiple RF chains, MIMO technology can easily scale wireless link capacity. However, the high power consumption and circuit area cost prevents.

We motivate single RF-chain design by examining the energy cost of existing multi-RF-chain MIMO Wi Fi /ZigBee. Then, we empirically explore the feasibility of antenna index modulation/decoding.

Proposed System

1) Network generation: This will periodically send handshaking messages to their tower to ensure that they are functional, and also report changes to the one-hop neighbors. Missing messages can be used to detect the failure of these. Once a failure is detected in the neighborhood, the one-hop neighbors of the failed the would determine the impact

.

2) Capacity identification: limits of data transmission of each tower nodes in the smallest block to reduce the recovery overhead. The smallest block is the one with the least number of nodes and would be identified by finding the reachable set of nodes for every direct neighbor of the ailed node and then picking the set with the fewest nodes. Since a critical node will be on the sho path of two nodes in separate blocks, the set of reachable nodes can be identified. In other words, two nodes will be connected only if they are in the same block.

3) Changing the path: If tower is the neighbor of the tower that belongs to the smallest block, it is considered the to replace the fail path. Since it is considered the gateway of the failed path (and the rest of the network), we refer to it as "parent." A node is a "child" if it is two hops away from the failed node, "grandchild" if three hops away from the failed node, and so on.

4) The foregoing discussion has assumed that system are aware of the network topology and can assess the impact of the failure and uniquely identify which node should replace the failed the. If every tower in the network is communicating with all the other nodes, it would be possible to fully populate the routing table and for the individual nodes to reach consistent decisions without centralized coordination.

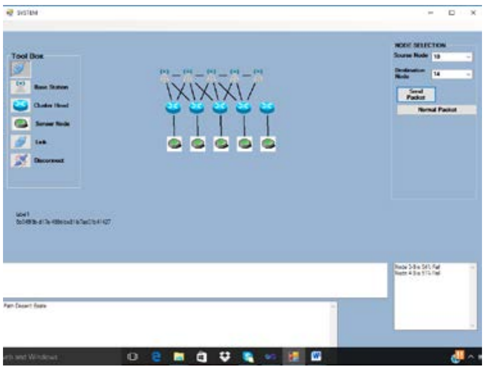

Fig 1. Data Transmission system

Conclusion

We have explored the feasibility of bringing multi-antenna benefits to single RF-chain wireless devices. Our findings are synthesized in a practical cross-layer design, ,that uses antenna index to carry extra bits and adaptive antenna hopping to ensure robustness/efficiency of communication. modulation/decoding components are simple and built from existing WiFi/ZigBee modules. By integrating antenna hopping with the inherent modulation structures of such practical wireless systems, Halma is able to achieve multiple folds of capacity gain – even higher than existing theoretical prediction. Thus, represents a viable and effective means of realizing multi-antenna networking between energy-constrained wireless devices.

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