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Reliable Multi-Hop MISO Based Cooperative Communications for Energy-Constrained Wireless Sensor Networks

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ABSTRACT

The dynamic and lossy nature of wireless communication poses major challenges to reliable, self-organizing multi hop networks. These non-ideal characteristics are more problematic with the primitive, low-power radio transceivers found in sensor networks, and raise new issues that routing protocols must address. Link connectivity statistics should be captured dynamically through an efficient yet adaptive link estimator and routing decisions should exploit such connectivity statistics to achieve reliability. Link status and routing information must be maintained in a neighborhood table with constant space regardless of cell density. We study and evaluate link estimator, neighborhood table management, and reliable routing protocol techniques. We focus on a many-to-one, periodic data collection workload. We narrow the design space through evaluations on large-scale, high-level simulations to 50-node, in-depth empirical experiments. The most effective solution uses a simple time averaged EWMA estimator, frequency based table management, and cost-based routing.

INTRODUCTION

INwireless networks, energy efficiency is a dominating design criterion. It is well-known that for the same through-put requirement Multi Input Multi Output (MIMO) systems require less transmission energy than single input single output (SISO) systems in the presence of fading [1]. However, it is usually infeasible to mount multiple antennas on small wireless devices due to the required minimum separation of these antennas. To achieve MIMO gains in wireless networks, cooperative (virtual) MIMO techniques have been proposed [2]. There is an increasing interest in translating the advantages of using virtual MIMO at the physical layer into higher layer performance benefits to maximize network throughput, or minimize total energy consumption and end-to-end delay [3-8]. In previous works, energy efficiency of cooperative transmissions over a single hop was investigated and compared to the traditional SISO transmissions [4, 5]. The capacity of a large gaussian relay network, where a source cooperates with relay nodes to transmit to a sink node is investigated in [8]. In our work, we investigate energy efficient routing in multi-hop wireless networks with cooperative transmissions when the channel is slowly-varying. Unlike [8], transmissions are required to satisfy an outage probability requirement, which is a suitable metric for this channel model. Also, [8] includes unreliable transmissions between source and relay nodes, which is omitted in the present work. The key advantage provided by the cooperative transmissions considered in this work is the increase in the transmission range due to diversity gain when all radios transmit at the same fixed power level as in traditional SISO systems.

Our objective is to determine in a Multi-hop network. The optimal number of cooperating nodes per hop to minimize the end-to-end total energy consumption while satisfying an outage probability requirement at each hop. In order to identify the effect of the number of cooperating nodes on energy consumption, all other parameters, i.e., transmission power, rate and reliability are kept constant. The theoretical analysis of this problem is performed for networks with unlimited node density. Our results indicate that cooperative transmission is especially useful in Multi-hop networks with low propagation loss coefficient, stricter outage probability requirement, and lower transmission power level. A new greedy geographical routing algorithm suitable for vMISO transmissions is de-signed to demonstrate the applicability of our results for more general networks. The letter is organized as follows: In Section II, we discuss the system model and give the necessary background on vMISO systems. In Section III, we calculate and compare the energy consumption of vMISO and SISO systems under high node density assumption. In Section IV, we develop and analyze a greedy vMISO geographical routing algorithm. Due to recent technological advances, the manufacturing of small and low cost sensors became technically and economically feasible.

The sensing electronics measure ambient conditions related to the environment surrounding the sensor and transforms them into an electric signal. Processing such a signal reveals some properties about objects located and/or events happening in the vicinity of the sensor. A large number of these disposable sensors can be networked in many applications that require unattended operations. A Wireless Sensor Network (WSN) contain hundreds or thousands of these sensor nodes. These sensors have the ability to communicate either among each other or directly to an external base-station (BS). A greater number of sensors allows for sensing over larger geographical regions with greater accuracy. Basically, each sensor node comprises sensing, processing, transmission, mobilizer, position finding system, and power units (some of these components are optional like the mobilizer). The same figure shows the communication architecture of a WSN. Sensor nodes are usually scattered in a sensor field, which is an area where the sensor nodes are deployed. Sensor nodes coordinate among themselves to produce high-quality information about the physical environment. Each sensor node bases its decisions on its mission, the information it currently has, and its knowledge of its computing, communication, and energy resources. Each of these scattered sensor nodes has the capability to collect and route data either to other sensors or back to an external base station(s)1. A base-station may be a node or a mobile node capable of connecting the sensor network to an existing communications infrastructure or to the Internet where a user can have access to the reported data.

A. Steps involved in multihop cooperative algorithm

Create a Greedy geographical routing (GR) network in which nodes are random in nature and distributive in approach In GR n/w node forwards a packet to its neighbor that is geographically closest to the destination.

Discover conventional routes R1, R2, R3……….Rn from source to destination nodes.

R=particular route from source to destination node. R=N1-N3-N5

Discover neighbor nodes which are optimally cooperative having minimum power.

Segregate cooperative nodes to different power limits P1, P2,P3 ,P4………………… Pn. P= each path power

Calculate energy consumption E at each cooperative min power node to transmit k bits to a distance d with n cooperating nodes to find out each path power.

$$E\ (k\ ,d\ ,n)\ =\ \ kE_e\left[n\ +\ E_a E\ _e + \frac{1}{r_n}\left(n\ \left(1\ + \frac{E_a}{E_e}\right) +\ 1\right)\right]$$

k=no. of bits to be transmitted

n=no. of cooperative nodes r_n =transmission ratio $r\ _n = k_n$

Where k_n = tot no. of bits that are possible to transmit

(capacity).

E_a =transmission power.

E_a =receiving power.

Cumulative path power is given by

P1 = $E_1 + E_2 + E_5$

P2 =

Pn =

Choose the optimal path such that nodes are optimally cooperative having the maximum power path

P_{opt} = max (P1, P2… Pn).

Establish communication in a n/w along optimal path with different factors (k, d, n).

Evaluate performance of threshold power (P_th), Route overhead,

Delay, Route life, n/w life.

Algorithm: multihop(n5,i1,i2)

Input : n5,k n5=no of nodes

i1=source ID

i2=destination ID

Output : optimal cooperative path

1. fori=20:5:35

n5=i

2. bndl=creat_ntw1(n5,kk);

3. g1=neighbour_discover_siso(bndl,n5);

4. g2=neighbour_discover_vmiso(bndl,n5);

```
5.  evaluate_route(i1,i2,bndl,g1,n5);
6.   evaluate_route(i1,i2,bndl,g2,n5);
7.  %Routing Request%
8.   if((i1<=n  & i2<=n)&(i1>0 & i2>0) & (i1~=i2))
        % validation checking for nodes
        t1=bndl(1:2,i1);                  % source id
        t2=bndl(1:2,i2);        %destination id
end
9.   evlenergy_siso(p1);
10.  evlenergy_miso(p2,dv);
11.   end for
12.  Plot optimal path(siso)
13. Plot optimal path (miso)
14.  End
```

The MISO Planning Approach

MISO is guided in its planning efforts by a set of principles established by its Board of Directors. These principles were created to improve and guide transmission investment in the region and to furnish anelement of strategic direction to the MISO transmission planning process. These principles, confirmed are as follows:

- Guiding Principle 1: Make the benefits of an economically efficient energy market available to customers by providing access to the lowest electric energy costs.
- Guiding Principle 2: Provide a transmission infrastructure that safeguards local and regional reliability and supports interconnection-wide reliability.
- Guiding Principle 3: Support state and federal energy policy objectives by planning for access to a changing resource mix.
- Guiding Principle 4: Provide an appropriate cost mechanism that ensures the realization of benefits over time is commensurate with the allocation of costs [9].

- Guiding Principle 5: Develop transmission system scenario models and make them available to state and federal energy policy makers to provide context and inform the choices they face.

To support these principles, a transmission planning process has been implemented reflecting a view of project value inclusive of reliability, market efficiency, public policy and other value drivers across all planning horizons studied. A number of conditions must be met through this process to build long-term transmission that can support future generation growth and accommodate new energy policy imperatives. These conditions are intertwined with the planning principles put forth by the MISO Board of Directors and include:

- A robust business case for the plan.
- Increased consensus around regional energy policies.
- A regional tariff matching who benefits with who pays over time.
- Cost recovery mechanisms to reduce financial risk.

The following activities were undertaken to fulfill these conditions and—through them—the planning

principles enunciated by the Board of Directors:

- Safeguarding local and regional reliability: System reliability must be maintained throughout all MISO planning efforts, both on a local and interconnection-wide basis. This requirement can be difficult, in the face of changing generation and energy policy standards. Throughout 2011, MISO continued the transformation of the planning process to create an integrated transmission network that supports current and future reliability needs, while minimizing the cost of delivered energy. This value-based planning approach demonstrates a robust view of project benefits, through the analyses of many potential reliability, economic and policy-driven variables.
- Distributing benefits commensurate with costs: The MISO planning approach is premised on the allocation of transmission costs in a manner that is commensurate with their benefits. To ensure this goal was met, MISO created a complete business case for the proposed Multi Value Project portfolio which demonstrated the regional spread of the economic benefits of the portfolio. In the future, MISO will continue to refine the business case for transmission

projects and portfolios, as staff seek to optimize the transmission system to deliver the least-cost energy to consumers.

- Responding to evolving energy policy: MISO examines multiple future scenarios in order to capture the impact of a wide array of potential policy outcomes[10]. These future scenarios include varied demand and energy growth levels, and they also include the implementation of new policies which may have large impacts on the transmission system. For example, MISO conducted a thorough analysis of the U.S. Environmental Protection Agency (EPA) regulations to determine the impacts and action which will need to be taken as the regulations go into effect.

B. Investments in system reliability and efficiency

To respond to existing energy mandates and safeguard the system reliability, MTEP11 recommend 215 new projects for inclusion in Appendix A. These projects represent an incremental $6.5 billion in transmission infrastructure investment within the MISO footprint and fall into the following four categories:

- Multi Value Projects (16 projects, $5.16 billion): Projects providing regional public policy, reliability and/or economic benefits.
- Baseline Reliability Projects (40 projects, $424 million): Projects required to meet North American Electric Reliability Corporation (NERC) reliability standards. These standards impact facilities of a voltage greater than 100kV and represent the minimum standard applied across the MISO footprint.
- Generator Interconnection Projects (26 projects, $273 million 7): Projects required to reliably connect new generation to the transmission grid. The projects recommended for approval will allow for the connection of approximately 2,700 MW of wind, nuclear, and other generation
- Other Projects (133 projects, $681 million): [11] A wide range of projects, such as those designed to provide local economic benefit but not meeting the threshold requirements for qualification as Market Efficiency Project (MEP), and projects required to support the lower voltage transmission system.

The addition of new transmission projects in MTEP11 brings the total number of projects in Appendix A to 553, representing an expected investment of $10.0 billion through 2021. When completed, the projects will result in approximately 6,600 miles of new or upgraded transmission lines. Since the first MTEP cycle closed in 2003, transmission projects recommended for approval total $14.3 billion, of which $4.3 billion is associated with projects already in service.

MTEP11 contains 24 new Appendix A projects meeting cost-sharing eligibility criteria under the Baseline Reliability Project or Generator Interconnection provisions of the MISO Tariff. This report also features 16 projects meeting Multi Value Project cost sharing methodology criteria.

CONCLUSIONS

The effect of time synchronization errors in a cooperative MISO system was investigated. The clock jitter at the transmit cluster causes ISI, thereby reducing the mean of the received signal and increasing the variance of the noise. An analytic expression for the average SINR is derived that gives insight into how the clock jitter affects the system. The power penalty entailed in a static channel due to the transmit clock jitter turns out to be independent of the number of transmit nodes and islarger for higher SNRs. Simulation results indicate that 10% jitter does not have much effect on the BER performance of the cooperative transmit MRC and Alamouti techniques. We find that a SISOsystem with the same transmit energy outperforms the worst case BER performance of the transmit MRC and Alamouti schemes for jitters greater than 80% and 50%, respectively, and there is no benefit in cooperative transmission for very large clock jitters. Since the cooperative MISO scheme has a good tolerance of up to 10% jitter, the synchronization algorithms can be made simpler and more energy efficient without sacrificing the performance of the system.

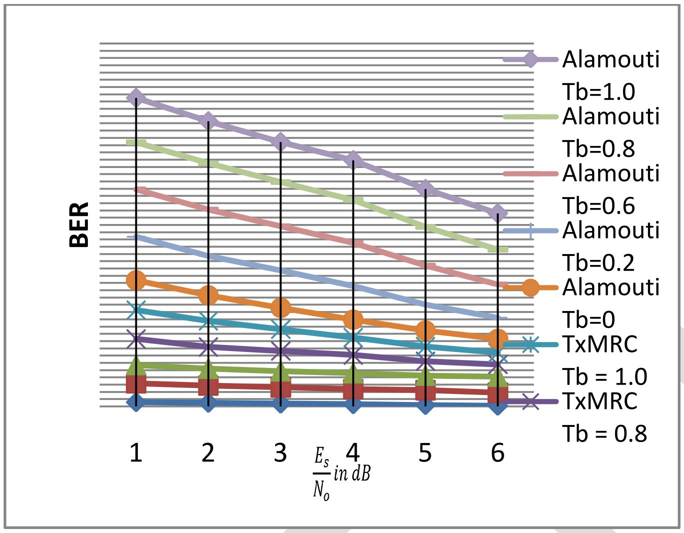

Fig.10. Comparison of the 2 × 1 transmit MRC and Alamouti schemes.

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