Cooperative MIMO Techniques in Wireless Communications with Security Concern

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1. Concepts and objectives

Multiple-input multiple-output (MIMO) wireless [1] uses different waveforms on typically two, but sometimes three or more transmitting antennas inputting to the channel carrying radio waves from Point A to Point B. Multiple antennas and radios (typically, two or three) also are applied to the output of the radio channel at the receiver, along with a lot of signal processing, which ideally improves range and throughput compared with simpler or traditional radio designs operating under similar conditions.

MIMO technology has attracted attention in wireless society because of significant increases in data throughput and link range without additional bandwidth or transmit power it brings. It achieves this by higher spectral efficiency (more bits per second per hertz of bandwidth) and link reliability or diversity (reduced fading).

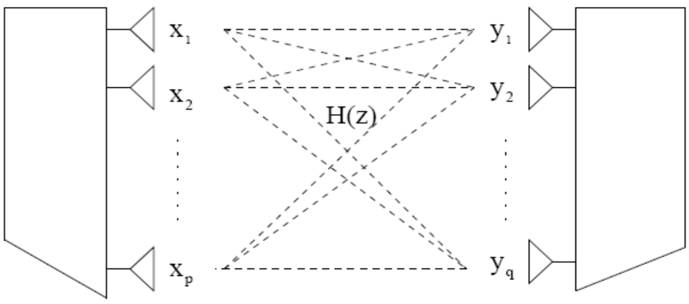

Figure 1. MIMO system structure

MIMO can be sub-divided into three main categories, precoding, spatial multiplexing or SM, and diversity coding. Precoding is multi-layer beamforming in a narrow sense or all spatial processing at the transmitter in a wide-sense. In (single-layer) beam-forming, the same signal is emitted from each of the transmit antennas with appropriate phase (and sometimes gain) weighting such that the signal power is maximized at the receiver input. Spatial multiplexing requires MIMO antenna configuration. Diversity Coding techniques are used when there is no channel knowledge at the transmitter.

The MIMO technique requires multiple transmitters and receivers; moreover, this puts a big burden for circuit design issue. Nowadays, researcher has noticed that while the wireless sensor network nodes are transmitting information they can take use of their neighbors' channel capacity thus we can form a distributed MIMO system over wireless environment. This technique takes use of cooperative communication between sensing nodes thus to achieve the share of antennas and channel resources. By transmitting and/or receiving information jointly, tremendous energy saving is possible for transmission distances larger than a given threshold, even when we take into account the local energy cost necessary for joint information transmission and reception.

Additionally, preliminary research has begun exploring MIMO as a solution technology for netted sensors. [2] [3] [4]

2. Progress beyond the state-of-the-art

To achieve our goals, we have general two potential ways: one is to improve the implementation efficiency of the MIMO system on chip thus to make every MIMO on each node possible. Meanwhile, we have observed the some new communication theory to enhance the

The second way comes from a promising observation that a virtual MIMO system formed by paralleled nodes. Cooperative communication and network are taken use among the distributed sensing nodes.

2.1 MIMO Implementation Saving

Since MIMO techniques require complex transceiver circuitry and large amount of signal processing that lead to increased power consumption at the circuit level it is difficult to directly apply MIMO techniques in the low-cost small-sized sensors. Moreover, physical implementation of multiple-transmit or receiver antennas on a small, energy-limited sensor might not be realistic. The total energy consumption includes both the transmission energy and the circuit energy consumption.

See M-LESQ work [5], Least Squares are extended to MIMO case which can be efficiently put into wireless network thus to decrease hardware implementation.

In [6]'s work, the authors propose a new method maximizing a lower bound for the product of SINR of MIMO by calculating a closed-form solution for antennas' weights.

2.2 Cooperative Communication and Network Theory

Cooperative diversity can provide gains in terms of savings in the required transmit power in order to achieve a certain performance requirement because of the spatial diversity it adds to the system.

In cooperative communications, independent paths between the user and the base station are generated via the introduction of a relay channel.

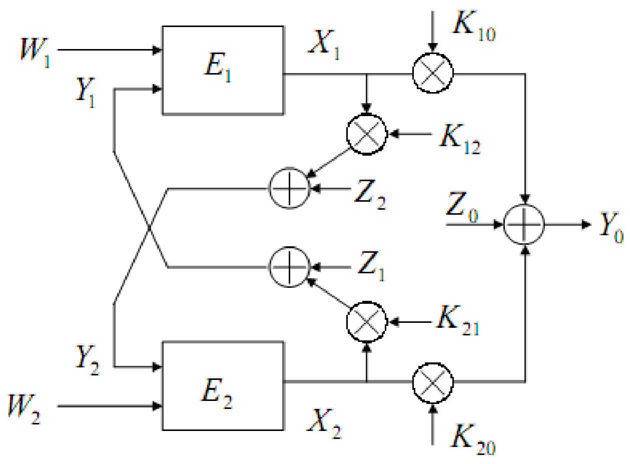

Figure 2. Block diagram of a fading Gaussian cooperative channel

A key aspect of the cooperative communication process is the processing of the signal received from the source node done by the relay. These different processing schemes result in different cooperative communications protocol. Cooperative communications protocols can be generally categorized into fixed relaying schemes and adaptive relaying schemes.

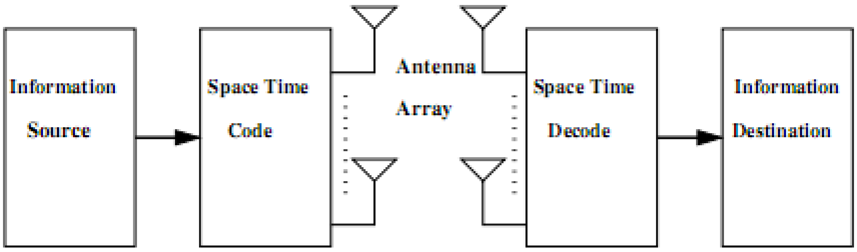

Figure 3. STC assisted cooperative MIMO system model

Another important factor in cooperative communication is the strategy to cooperative nodes selection [7]. The relay can sense the communication channel to detect empty time slots and we assume that the errors and delay in the packet acknowledgement feedback are negligible.

To enhance the selection strategy reliability, we should take full use of partial channel state information (at both source and relay) thus to achieve higher bandwidth efficiency.

Two major schemes can be categorized as followings:

i. Single relay;

An important issue in this scenario is: when to chose a relay instead of transmitting directly; one appropriate metric to measure relay's ability is to use a modified version of the harmonic mean function of its source relay and relay-destination instantaneous channel gain. By setting up a cooperation threshold and comparing with the ratio of S-D channel gain and relay's ability, we can make this mechanism easily to deploy.

ii. Multi-relays

N relays are considered as follows:

First, same as the single scheme, make a decision on when to make a cooperation;

Then we make a selection which one to chose for a cooperation, but chose only one when it needs. Optimal one is the one who has maximum instantaneous value of the relay's metric.

A further improvement with Control signal can be made to indicate the source's decision.

The system performances can be characterized in terms of outage probability which is defined as the event that received SNR falls below a certain threshold.

Meanwhile, there're several implementation of cooperation in network model, such as cooperation in MAC protocol and cooperative routing schemes.

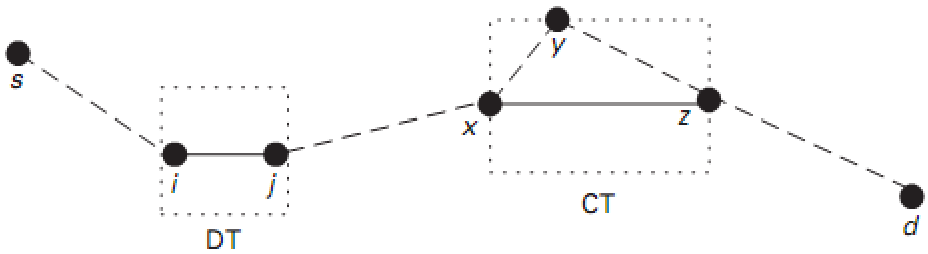

Figure 4. Cooperative network

Network model and transmission modes for wireless networks environment can be found in Figure 4.

As cooperative model best suits in the wireless sensor network and energy requirement is the most significant concern, we chose the energy consume as the most critical parameter when chosing suitable path.

The power formulas for this routing algorithm can be distributively implemented by the Bellman-Ford shortest path algorithm. [8]

First, each node calculates the costs (required powers) of its outgoing links, and then applies the shortest-path Bellman–Ford algorithm using these newly calculated costs; second, the distributed Bellman–Ford shortest-path routing algorithm is implemented at each node.

3. MIMIO-WSN System Architecture

3.1 Schemes for Virtual MIMO

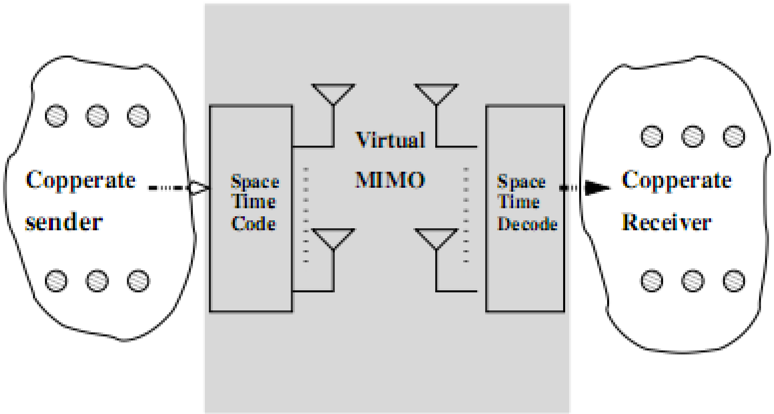

Fig 3 Virtual WSN System Architecture

Based on the nature of sensor network, energy is the key point concern in its development and design. Thus many techniques have been proposed to prolong the lifetime of this promising network structure. For example, recent hardware techniques allow more signal processing functionality to be integrated into sensor node with limited power supported chips. Here we introduce a virtual MIMO system by borrowing the ideas of promising features of MIMO.

A same similar system has been proposed by Li taking use of Space-Time-Code [9]. Also Li proposed a delay and channel estimation scheme without transmission synchronization for decoding in virtual MIMO scheme in this paper. Meanwhile, some extensions and improvements on this STC have already been checked. [10]

In virtual MIMO scheme, we should form a clustered cooperative wireless sensor networks implementing cooperative transmission and reception of data. After the initialization, we implement a two-function oriented transmitter:

1. Data broadcast within cluster;
2. MIMO transmission between transmitter side and receiver side.

At the same time, we chose to take use of a simplified selection diversity receiver which will allow us to obtain the full receiver spatial diversity. Energy performance can be improved by different diversity strategies.

This transmission protocol can be divided into two phases: intra-cluster and inter-cluster. While the inter-cluster scheme can be defined as a time division, decode and forward, multiple relay channels taking use of space time code, the intra-cluster transmission can be modeled simply as a broadcast channel.

A common question in cluster-based system is the chosen of cluster head. In our proposed system, we take the use of Channel State Information and the authentication information from up layer (with the help of cross layer design, will be illustrated in the following parts). During each cluster forming phase, the head decision will be calculated upon the broadcast of each nodes' such information.

3.2 Cross Layer Design for Wireless Sensor Network Taking use of Cooperative MIMO

A challenge is that STBC require antenna array and synchronization among transmitting antennas, neither of which is available in sensor networks with low-cost small-sized sensors. A self-organize and cross layer based MIMO protocol is needed for establishing a multi-hop virtual MIMO system with concerns on efficiency. Actually, many papers showed that cross-layer integration truly improve the energy efficiency.

Energy efficiency, reliability and QoS provisioning in WSN are inter-related and affected by Physical, MAC, network and transport layers. All these issues should be considered jointly to maximize the sensor system efficiency. [11]

Most researchers use the clustered architecture in the research of virtual MIMO cross layer design [12]. The methods can give a relationship between the energy consumption and system parameters, as data rates, transmission power, antenna numbers, modulation scheme, delay and so on. These parameters can cooperate to help achieve a better efficiency, like system power consume.

However, the cross-layer action usually decreases the level of modularity, which makes it more difficult to further design. Meanwhile, the instability is increased.

Our potential works in those issues will be focused on the following aspects:

1. Cross layer resource allocation;
2. More intelligent understanding of energy consumption;
3. Accurate delay modeling.

4. Virtual MIMO system based detection for security issues

The issues of privacy and security in wireless communication networks have taken on an increasingly important role as these networks continue to flourish worldwide. Compared with wire-line networks, wireless networks lack a physical boundary due to the broadcasting nature of wireless transmissions. Those users finishing a silence period need to contend for channel access over a shared resource. At the same time, the use of cooperation increases the system performance by helping users in talk spurts to reduce the probability of dropping packets and having to contend again. By taking use of diversity advantages, the cooperative scheme can help achieve malicious detection and response mechanism. [13] [14]

We've firstly set up a virtual MIMO detection model for malicious node or low-ability node in wireless sensor network.

In a typical sensor network, malicious nodes with behavior affecting formal communication have been examined [15]. These nodes can be classified as followings:

1. Node with low ability, such as energy constrain;
2. Hold up packages with no relaying, also can be named as selfish node;
3. Sending out garbled information on purpose.

By jointly recognizing of garbled information using Virtual MIMO structure, we can have a relative accurate detection of malicious nodes and thus to take a further action to eliminate the unnecessary linkage of energy with the existing of malicious behaviors.

Afterwards, we combine cryptographic techniques, such like the classical PKI scheme, implemented in the higher layer with the physical layer security scheme using MIMO systems to provide stronger security for wireless networks [16].

Therefore the transmitter can communicate with the intended receiver and prevent the attacker from decoding the message at the same time. The process of adding artificial noise is controlled by upper-layer cryptographic techniques. In our approach the physical-layer can utilize upper-layer encryption techniques for security, while physical-layer security techniques can also assist the security design in the upper-layer.

5. Simulation

This system will offer more channels between the sensor nodes and the base station at the same frequency band, thereby increasing spectral efficiency. The design offers remote monitoring system with MIMO wireless sensor network [17].

This proposal will simulate the design and implementation of a Multiple-Input/Multiple- Output (MIMO) system for Wireless Sensors Networks (WSN) under the SensorSim [18].

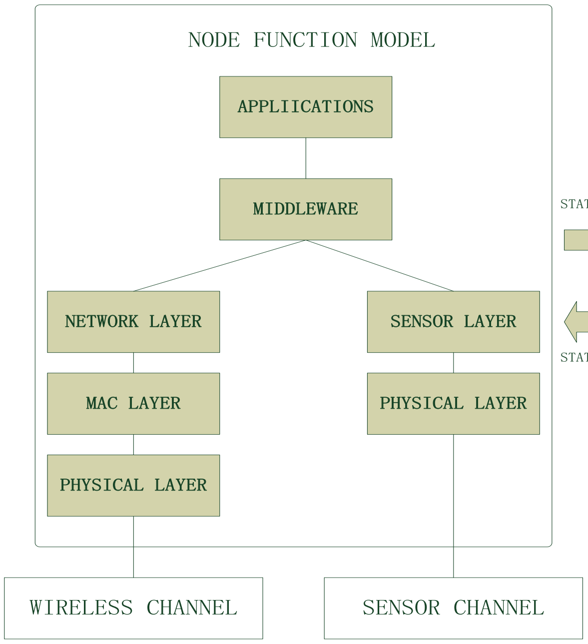

Figure 4. Sensor Node Model in SensorSim

Let's first take a look at what we want from this simulation. First, the platform should perform the simulation of our proposed algorithm. Second, it should include a model for wireless transmissions and battery models (quite important for sensor network). Third, it should be scalable and efficient for large scale simulation. And last, there should be technical support.

SensorSim is a good extension to NS2 environment. Most importantly, it provides robust battery models, radio propagation models and sensor channel models.

6. Prototype implementation

We try to integrate the proposed system and the cooperative module into TinyOS [19] and setup a test run on Crossbow.

TinyOS is a free and open source component-based operating system and platform targeting wireless sensor networks (WSNs). TinyOS is an embedded operating system written in the nesC programming language as a set of cooperating tasks and processes.

TinyOS programs are built out of software components, some of which present hardware abstractions. Components are connected to each other using interfaces. TinyOS provides interfaces and components for common abstractions such as packet communication, routing, sensing, actuation and storage.

The TinyOS system, libraries, and applications are written in nesC, a new language for programming structured component-based applications. The nesC language is primarily intended for embedded systems such as sensor networks. nesC has a C-like syntax, but supports the TinyOS concurrency model, as well as mechanisms for structuring, naming, and linking together software components into robust network embedded systems. The principal goal is to allow application designers to build components that can be easily composed into complete, concurrent systems, and yet perform extensive checking at compile time.

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