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Study of Performance of Cooperative Virtual MIMO System for WSNs.

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Abstract: *MIMO techniques can be used to boost data rates while maintaining a constant bit error rate (BER) and transmission power. A cooperative Virtual MIMO system design rather than a True MIMO system architecture is thought to be more practical for wireless sensor network (WSN) applications due to thetiny form factor, energy, and computational constraints of wireless sensor nodes. In order to improveWSN performance, virtual MIMO with Vertical-Bell Labs Layered Space-Time (V-BLAST) multiplexing architecture has recently been developed. For the first time, we assess the performance of a cooperative Virtual MIMO system based on V-BLAST architecture with multi-carrier modulation techniques in this study as we further explore the effects of various modulation approaches. Both communication and processing energy can be measured using analytical models and simulations that make use of real hardware and environmental conditions. Evaluations are done on the BER, spectral efficiency, and overall time delay of numerous cooperating nodes, each with a single antenna. The findings demonstrate that cooperative Virtual-MIMO with Binary Phase Shift Keying-Wavelet based Orthogonal Frequency Division Multiplexing (BPSK-WOFDM) modulation is an effective approach for upcoming high data-rate and energy-efficient WSNs.*

Keywords: cooperative virtual MIMO; wavelet based OFDM; V-BLAST; wireless sensor networks

1. Introduction:

Low power and low cost WSNs can now be used in numerous real-world applications, including as environmental monitoring, home automation, traffic management, precision agriculture, and health care, thanks to advancements in Micro-Electro-Mechanical Systems (MEMS) technology. An emerging class of sensor networks that can enable automated real-time interpretation of circumstances in the monitored environment is wireless multimedia sensor networks (WMSNs), where sensor nodes are capable of producing various media streams (audio, video, image, textual, and scalar sensor data). These sensor networks may be used for monitoring national borders and public areas, seismic monitoring, wildlife habitat monitoring, in-home emergency detection for the old and sick, mixed reality networked gaming, and process quality control. However, data rates that are required for multimedia materials like picture or video streams are orders of magnitude higher than what can be supported by current WSNs. Due to the fact that embedded sensors are often battery-powered, they are also energy-constrained. Good data speeds and high energy efficiency are therefore crucial concerns in such networks that must be addressed.

Bit error rate (BER) can be reduced utilising spatial diversity, and data rate can be increased using MIMO techniques by applying spatial multiplexing. Along with beam forming methods, MIMO techniques can be utilised to increase signal to noise ratio (SNR) at the receiver and to reduce co-channel interference (CCI). MIMO systems use more energy due to their increased circuit complexity. Circuit energy consumption in long-distance transmission is often substantially lower than transmission energy consumption. Circuit energy consumption, however, can be comparable to transmission energy consumption in short-distance transmission. Therefore, one must consider both circuit and network performance when evaluating the performance of MIMO approaches in energy-limited WSNs, where sensors are typically powered by batteries or other exhaustible energy sources and transmission energy consumption.

This study focuses on V-BLAST-based cooperative virtual MIMO systems for wireless sensor networks. In particular, it examines how well such systems function when using various modulation techniques, such as multi-carrier modulation techniques, which, as far as we are aware, have not yet been examined in literature for such systems. Fourier-based OFDM (FOFDM), WOFDM, BPSK-FOFDM, BPSK-WOFDM, M-ary Quadrature Amplitude Modulation (QAM), M-ary Differential Quadrature Phase Shift Keying (DQPSK), and M-ary Offset Quadrature Phase Shift Keying are among the modulation techniques taken into consideration (OQPSK). In comparison to other comparable studies, the research is conducted over a wider variety of performance parameters, including BER, energy efficiency, spectrum efficiency, and time delay performances. Another important addition of this article is the extensive modelling and analysis of the processing (CPU or central processing unit) and communication (circuit and transmission) energy consumption of WSN nodes in various operational modes. The study's findings can shed light on certain performance factors and point to potential fixes for high data-rate, low-power WSNs in the future.

2. Related Work:

For the same throughput and BER, the energy and delay performances of a cooperative virtual MIMO system with Alamouti coding for WSNs were examined and compared with SISO system. With consideration of circuit and transmission energy usage, the performance was further contrasted over various transmission distances. Alamouti coding is an STC approach that uses multiple antenna configurations and space and time (two-dimensional) coding to achieve coding gain and diversity gain at the same bit rate, transmission power, and bandwidth as a single antenna system. Information bits are sent using STC techniques in a specific transmission order. The received signals are merged at the receiver using the best combining strategy, which is then followed by a decision rule for maximum likelihood detection.

There is no longer any need for spatial encoding on transmitting side nodes thanks to a V-BLAST based virtual MIMO WSN with QAM that was suggested in. This eliminates the need for local communication and the associated synchronisation requirement on transmitting side nodes. The application of WOFDM with V-BLAST based WSN was proposed in and analysed under a co-located true MIMO receiver architecture in order to increase the system's energy efficiency without compromising information security. In, various V-BLAST detection techniques were used to observe the BER performance of such devices.

Recently, a non-cooperative STC approach based MIMO system was developed with the introduction of smart antennas for WSNs. The system is more energy-efficient since it doesn't need local communication on the transmitter and receiver sides when employing a 2-element switching antenna array. A nonlinear MIMO technique was proposed to simplify the structure of MIMO WSN for energy consumption reduction, where real or imaginary parts of the complex-valued received signal were taken into consideration for further processing. This results in a simpler receiver architecture at the expense of some information loss.

3. Background:

3.1. Cooperative Virtual MIMO:

High system performance can be achieved using MIMO techniques without the need for increased bandwidth or power. However, it is frequently impractical to outfit each sensor with several antennas in order to perform MIMO due to the compact form factor and low energy of sensor nodes. Instead, to achieve virtual MIMO communication, a group of single-antenna sensor nodes might work together to create a virtual antenna array (VAA). Because numerous nodes are positioned at various physical placesin order to collaborate with one another, virtual MIMO systems are scattered in nature. Virtual MIMO canachieve the benefits of true MIMO techniques for WSNs with adequate timing and frequency synchronisation between constituent nodes of the VAA.

3.2. V-BLAST:

In order to achieve spectral efficiency at a specific data rate and transmission power, V-BLAST is a spatial multiplexing approach. It can enhance the number of supported sensors in the system or increase channel capacity to improve the single-sensor data rate. While standard wireless communication methods'spectral efficiency ranges from 1 to 5 bps/Hz (mobile cellular) to around 10 to 12 bps/Hz, it ranges from 20 to 40 bps/Hz (point to point fixed microwave system). A single user's data stream in V-BLAST can be divided into several sub-streams, or multiple users can send data at once. Since all sub-streams are transmitted simultaneously in the same frequency band using an array of transmitter antennas, the spectrum is utilised very effectively. Data from the user is transmitted simultaneously through several antennas. With more transmit antennas being employed, the effective transmission rate rises roughly proportionally. The number of receivers in this system is higher than, or equal to, the number of transmitters. The sub-streams that are being broadcast stand alone. The power of each transmitter is scaled by 1/Nt. Thus, regardless of the quantity of transmitters, the overall power remains constant (Nt).

3.3. Multi-Carrier Modulation:

A high data rate substream is demultiplexed into lower data rate substreams in the FOFDM multi-carrier modulation technology to lengthen each substream and decrease inter-symbol interference (ISI). Sine and cosine bases are used to create the orthogonal subcarriers, and the orthogonality is attained in a time window with a width equal to the symbol's duration. FOFDM is therefore not band-limited. The side lobes produced by each subcarrier lead to inter-carrier interference (ICI), which is then exacerbated by the multipath channel effect, which also results in a rise in ISI. Each FOFDM symbol has a cyclic prefix (CP)/guard interval (GI) appended to it to get around this issue, albeit at the expense of transmission efficiency.

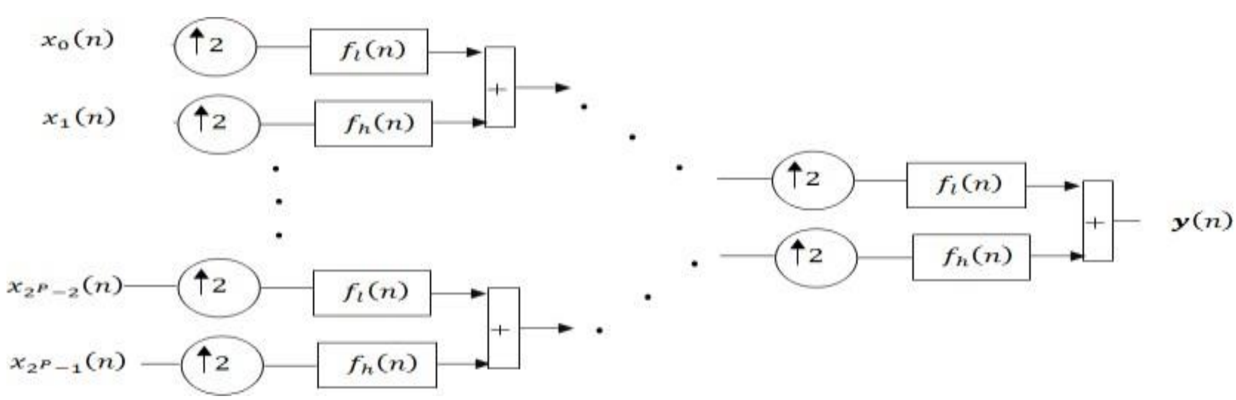

Fig 1.Symmetric multistage synthesis side QMF bank

4. System Model:

We consider a wireless communication link between Nt data sensing nodes (DSNs) acting as a single Virtual MIMO transmitting side node and a single Virtual MIMO receiving side node made up of a single-antenna Data Gathering Node (DGN) and a single-antenna Data Assisting Node (DAN), as shown in Figure 2

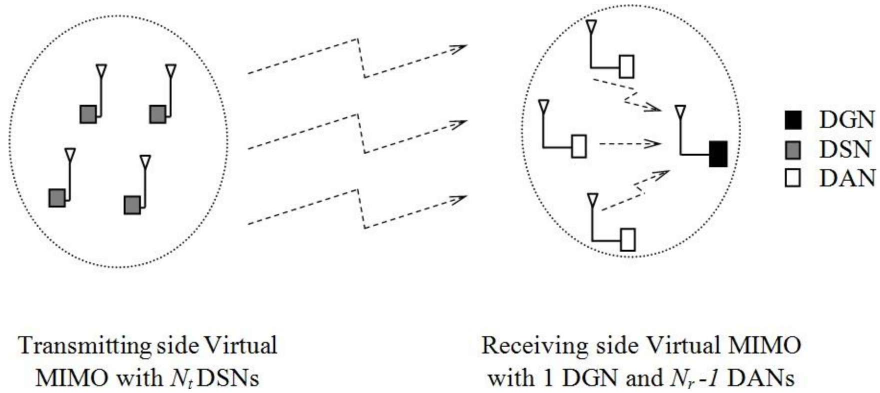

Figure 2. Communication between Transmitting and Receiving side Virtual MIMO nodes

5. Parametric Modeling of System Characteristics:

5.1. Energy Consumption:

In order to keep the energy consumption model straightforward, the energy used in baseband signal processing blocks was ignored. However, we have also calculated how much energy baseband (Digital) signal processing blocks need in this paper. In contrast to the DSNs and DANs, the DGN (typically a more resourceful node acting as a drain) is thought to have no energy limits.

RF (Analog) Energy Consumption:
Long-haul communication (from DSNs to receiving side DANs and the DGN itself) and receiver side local communication account for the majority of the RF section's energy consumption (from DANs to DGN). Power consumption of all power amplifiers and power consumption of all other circuit blocks make up the majority of the total average power consumption along the long-haul signal path. Assuming a linear relationship between transmit power and power amplifier power consumption:

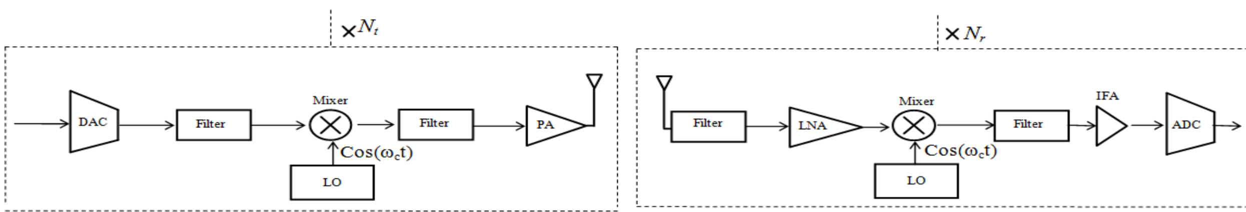

Figure 3. Transmitter and receiver architecture for WOFDM (analog).

Base Band (Digital) Energy Consumption:

Odyssey's prediction model is used to estimate a processing block's CPU cycle count. The value of TelosB mote energy consumption per CPU cycle is multiplied by the projected number of CPU cycles to determine the base band energy consumption of a block. By multiplying the estimated number of CPU cycles of the modulation processing block by the energy consumption per CPU cycle and dividing it by the total number of bits, it is possible to determine the energy consumed per bit by the CPU during modulation, which also represents the base band energy consumption in transmit (Tx) mode. Similar calculations can be used to determine the base band energy consumption in receive (Rx) mode, which is the sum of the CPU's energy consumption per bit during demodulation and V-BLAST detection.

Evaluation Results:

Using Matlab/Simulink simulations, it was determined how BER performance varied with bit-energy to noise-spectral density ratio Eb/No for 16-DQPSK, 16-QAM, 16-OQPSK, 16-FOFDM (without cyclic prefix), 16-WOFDM (4-level symmetric with Haar filter coefficients), and 16-BPSK-16FOFDM with four DSNs (as one transmitting Virtual-MIMO node) and one As a result, the system consists of eight nodes, each with a single antenna. As one of the most popular tools for physical layer modelling of wireless systems with various digital communication blocks and analysis tools available for assessing system performance, Matlab/Simulink is utilised as the simulation platform. Additionally, Matlab/Simulink code can be easily converted into C and high definition languages (HDL) for real hardware implementation..

Each DSN's information source generates data at a 250 kbps rate in accordance with the IEEE 802.15.4-2009 standard for WSNs. IEEE 802.15.4-based radio transceivers typically have a transmission range of 10–20 m, with a notional maximum range of roughly 100 m in clear line-of-sight circumstances. As a result, in this paper, the distance between the transmitting and receiving clusters is chosen at 20 m.

Information bits are modulated into a symbol stream at each DSN using 16-DQPSK, 16-QAM, 16-OQPSK, 16-FOFDM, and 16-WOFDM. At the DGN, the channel response matrix H is presumptively known in order to use the QR decomposition detection technique to identify the signals that have been received. Each performance graph has its 95% confidence interval plotted on it.

Due to their low BER performance and complicated RF architecture, 16-QAM and 16-DQPSK based systems are found to be the least energy-efficient, with the former being the more important reason. Even though 16-DQPSK has worse BER performance than 16-QAM, both approaches performed nearly equally well. This is because 16-DQPSK's lower PAPR led to nearly identical RF (Analog) energy consumption performance across the two approaches. Due to its superior BER performance and lower PAPR, the 16-OQPSK system outperforms the 16WOFDM and 16FOFDM systems. Compared to 16- FOFDM, a system based on 16-WOFDM uses about 40% less energy because of its simpler RF architecture, which lowers the amount of circuit energy it requires. For the same reason, it is discovered that BPSK-16WOFDM uses a comparable amount less energy as BPSK-16FOFDM. Additionally, it has been found that BPSK-16FOFDM and BPSK-16WOFDM use less energy than 16-FOFDM and 16- WOFDM, respectively, mostly because their PAPR is lower. Due to improved BER performance, it is evident that virtual MIMO systems use less energy than SISO systems.

Table 1 displays the base band energy consumption per bit per node for all modulation types together with the energy that each modulator, demodulator, and detection algorithm uses to make up that energy.

Due to their more sophisticated computations, it is found that each modulator uses more energy than a demodulator (in terms of CPU cycles per bit). 16-DQPSK uses less energy than other modulation algorithms for similar reasons. The of BPSK-16WOFDM with virtual MIMO is higher in comparison to that of the SISO system since it does not require V-BLAST detection on the receiver side (therefore is negligible).

Modulation Type	per bit in dBJ	per bit in dBJ	per bit in dBJ	per bit per node in dBJ
16-DQPSK	–31.7203	–32.1389	–30.7033	–31.2591
16-QAM	–31.2628	–31.9686	–30.7033	–30.9803
16-OQPSK	–30.8951	–31.1203	–30.7033	–30.4600

16-FOFDM	–30.0134	–30.7192	–30.7033	–29.8781
16-WOFDM	–31.0294	–31.7203	–30.7033	–30.8009
BPSK- 16FOFDM	–29.86	–30.587	–30.7033	–29.8167
BPSK 16WOFDM	–30.8764	–31.2681	–30.7033	–30.5142
SISO-BPSK-16WOFDM	–30.8764	–31.2681	–∞	–31.0678

Table 1. Base Band (Digital) Energy Consumption

The energy used by the CPU and radio transceiver in the sensor nodes, respectively, is referred to as base band (digital) energy consumption and RF (analogue) energy consumption. We presum both the radio transceiver and the CPU have two active states (Transmit and Receive). The CPU uses base band energy in transmit mode, which is dependent on the type of modulation used by the digital modulator to process each bit for transmission. On the other hand, the base band energy used by the digital demodulator and V-BLAST detection algorithm constitutes the CPU or processing energy usage in Receive mode.

We suppose that the radio transceiver goes into sleep mode, which is its only idle state, whenever it is not sending or receiving data. The radio components chosen to stay on during sleep state, which is design-specific, will determine how much energy the transceiver uses in sleep mode. The energy consumed in sleep mode is approximately 0.1% of the energy consumed in receive mode for the majority of existing transceivers for WSNs, which has an energy consumption ratio of about 0.001. The energy consumption of the transceiver in sleep mode may therefore be computed from (energy consumption by receiver circuits of the RF section per bit per node), which is discovered to be 34.8161 dBJ for 16-DQPSK, 16- QAM, and BPSK-16FOFDM.

For all modulation approaches, it is noted that is 1.75 s/bit, which is computed using Equation. Additionally, it was noted that the demodulator required less processing time than the modulator. This is so because modulating the signal requires more mathematical operations than demodulating. In comparison to and as a result of TelosB mote's slower processing speed, the overall processing delay is significantly higher. Therefore, for the overall virtual-MIMO time delay, is the most important time delay element. Due to its lower compared to the other six modulation schemes, the 16-DQPSK based system is determined to incur the least overall time delay, followed by the 16-QAM, 16-WOFDM, BPSK-16WOFDM, 16-OQPSK, 16-FOFDM, and BPSK-16FOFDM. is less than because no one uses the SISO system, which reduces.

6. Conclusions:

In the context of WSNs, this study examines the performance of a cooperative virtual MIMO system employing various modulation schemes. For a given transmission distance of 100 m, it is discovered that BPSK-16WOFDM outperforms other assessed modulation schemes in terms of BER performance by up to 95% and in terms of energy efficiency by up to a factor of two. However, DQPSK-based systems perform up to 23% better in terms of overall time delay. As a result, DQPSK-based systems can be a good choice for WSN applications that don't require a lot of time delay. SISO system performs better in terms of total time delay by 35%, however virtual MIMO system is 98% more energy efficient. Overall, BPSK-WOFDM has a lot of promise as a WSN solution because of its simplified RF section, reduced PAPR, and higher BER performance when combined with a cooperative virtual MIMO system architecture.

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