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Novel Hybrid-Relay Cooperative Communications Technique for Agriculture

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Abstract

Objective: To investigate, and analyse the novel Hybrid-Relay Cooperative communications technique and algorithms which provides the possibility of obtaining improved system performance, with minimal cost, complexities, and overall energy consumption in wireless fading channels while retaining spectral efficiency to aid decision making processes for a more efficient and effective water-agriculture-food nexus.

Methods: Henceforth, the comparative performance and energy efficiency analysis of the fundamental cooperative MIMO techniques namely: Detect & Forward (***DF***), Amplify & Forward (***AF***) and the Coded cooperation were analysed with respect to the Hybrid Cooperative Communications technique. The methodical and data-driven analyses were carried out using MATLAB and Wireless Communications Systems Parameters.

Results: In harmony with the 'Green Communications' wireless communication theme; the excellent trade – off between performance (data rate) and energy efficiency is confirmed, which of course creates very good potential for use for an improved agricultural monitoring and management system.

Conclusion: The Hybrid-Relay Cooperative communications system serves as a basis for the comparative analysis of the aforementioned cooperative MIMO techniques and provides fundamental, but meaningful deductions and potentials with regards to efficient cooperative communications for innovative, efficient and effective water management for improved agricultural practices and a sustainable environment.

Keywords: Agriculture, Hybrid-Relay Cooperative Communications System, Decode & Forward, Amplify & Forward, Coded Cooperative Communications, Cooperative Communications, Innovative

1. Introduction

All over the world, the issue of food security has been in the fore front of the campaign for sustainable development. Experience and news received from all over the world reveals that food security is dependent on effective agricultural practices. This also implies that areas with food shortages in the world would be required to step up agricultural production in the face of ravaging desertification caused by excessive draught and in the daunting face of global insecurity.

The challenge of food security necessarily suggests that global water management strategies need to be looked into in the light of improving agricultural development in sustainable manner. This is important to ensure year-round food production in areas with excessive dry season which includes Sub-Sahara African nations. Cameira and Pereira (2019) [1] identified land and water as primary determinants of agricultural output calling for an innovative approach to land and water governance. Similar challenges have been identified by A. Inocencio, Sally and Merrey (2003) [2] while providing an overview into the use of innovative approaches to agricultural water use for improving food security in Sub-Saharan Africa [3]. The World Bank, Food and Agricultural Organisation have at different times made similar calls for improvements in water management techniques, policies, strategies, systems, technologies globally to aid effective agricultural practices and ensure food security in the midst of challenges such as the reality of climate change.

Hence, the Innovative Analysis and Management of Water Resources for Effective Agricultural Practices has become a global concept. The concept seeks to foster effectiveness of global water resources management practices to enhance food production. It also seeks to design and promote a coordinated strategy for the development and management of water, land and related resources, to maximise agricultural yield.

Therefore, the increasing challenge of modern agriculture meeting up with the production of food for the continued increase in global population, in the context of the ever-growing competition for water and land, climate change, drought, anthropic water scarcity and less participatory water governance; requires urgent and a thorough approach for the good of humanity. For a data-driven world of ours, innovative measures to analyse and recommend effective and efficient water management techniques and approaches becomes relevant and would help overcome challenges associated with field study; by providing cost effective, efficient, intelligent and safer measures to ensure better decision making for more effective water management policies to increase agricultural output efficiency and environmental sustainability.

Therefore, innovative issues and measures must be applied in agricultural water management and practices for both field and system, to mitigate water scarcity, increase environmental friendliness and the welfare of society, and thereby increase food production.

The aim of this research work is to investigate and analyse factors and techniques that influences and aids water resources management, as used in the agricultural sector; and how water management techniques, systems, technologies, processes, policy decision making can be optimized for a more efficient water, agriculture and food nexus; with the use of wireless cooperative communications algorithms, methodologies and simulation tool.

2. Literature Review

2.1 Wireless Sensor Networks

Wireless sensor networks (WSN) are typically composed of nodes, which are distributed thickly and are able to sensor, pick up and transmit signals and information [4, 5]. The enablement of information to be captured is the core function of WSN's, using a set of sensors able to communicate with each other and process data inside the network itself (processing in-network) in order to do a specific set of tasks which cannot be done by humans due to their inherent limitations and physical survival conditions [6]. Additionally, the WSN can also be applied where there is ongoing need for environment monitoring(for example agriculture) and control and in tasks that would demand too much time and resources if manually done [7, 8]. This way, many applications like agriculture, electronic commerce, animal tracking and industrial activities, need their data to be available at real time. This real time concept is characteristic of applications which transactions must satisfy their deadline, so as to allow that data may be handled without losing its temporal validity. This enables the system to react in a efficient way, due to the obtained data correctness and consistency [9].

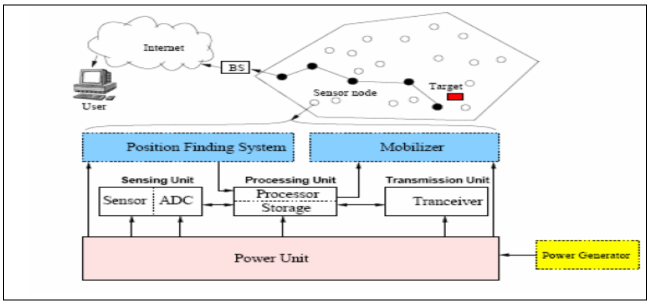

Fig 1: WSN Sensor Node General Structure [10]

2.2 Wireless Cooperative Communications

The method of cooperative communications, involves the creation of spatial diversity through an array of single antenna users combining to produce a 'virtual MIMO' system. The principle basically involves a user/node and its 'partner' node/mobile sending independent copies of the user's information to the destination (base station) at a given time [11, 12], to create a diversity called 'cooperative diversity', with the aims of improved overall performance and reduction in overall energy consumption; this therefore means that the baseline transmit power of the users/nodes will reduce as each user/node would need to transmit with a lesser power to achieve a target performance criterion. Therefore, users/nodes share their antennas and other resources to create a 'virtual MIMO' or spatial diversity system through distributed transmission and signal processing [13], thereby each users/nodes acts both as a source and a relay of information [14], unlike earliest works which was modelled according to the basic 'relay channel', where each user or node just forwarded or re- transmitted the signal it received, but not having its own signal to send; thereby assuming a 'memory-less' relay channel of which cooperation may not be possible when relay channel is poor [15].

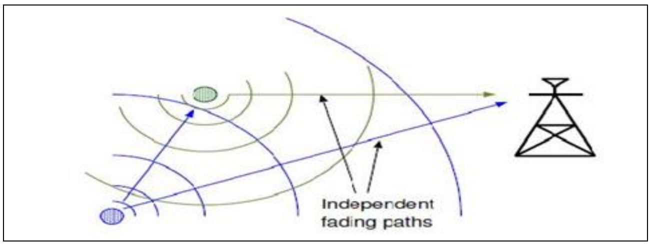

Fig 2: Cooperative Communication [14]

Work thus far generally considers that the users/nodes transmit equal power, but it could be possible to improve performance by varying user/node power based on the nature of the inter-user/node channel; therefore, this makes power control schemes an important factor in developing effective cooperative communications [14]. On Energy efficiency, it has been shown that both users/nodes in a two-user system obtain improved energy efficiency, saving a significant amount of energy through cooperation, though 'weaker' (lesser power) users/nodes benefit more than the 'stronger' (more power) users/nodes during cooperation [14, 16,17]. Also, much work has been done at the physical layer, at which cooperative methodologies are quite different from other higher protocol layers [14, 18, 19].

Furthermore, for reduced complexities and ease of analysis, most works have assumed mutually independent inter-user and uplink channels [14, 20], a perfect channel state information (CSI) at all receivers (users/nodes and base station) [16, 21, 22, 23, 24, 25]; though this may not always be the case practically, as the wireless channel could vary unpredictably; this of course has been considered by some works, where a feedback mechanism is used in the uplink transmission to address an imperfect CSI situation [26]. Additionally, works also analysed the MIMO techniques for cooperative communications based on a two user/node system [11, 17, 24, 25], that is to say each user just having one partner, this was also aimed at simplicity to avoid more complex algorithms for accurate partner assignment which is important in a much more practical multi –partner system;

and also a Rayleigh flat fading wireless channel type was assumed [11, 27, 25]; which is typical for a 'non–line of sight' (NLOS) system as in cellular wireless networks.

3. Methodology

3.1 Factors Influencing Water Management for Agriculture

Evidences have shown that for effective modern agricultural practices, adequate analyses should take into account influencing factors categorized as physical, agricultural and socioeconomic factors that act as drivers in the management of water resources as used in agriculture [28]. These factors are highlighted in the literature and must be properly investigated and analysed to ensure an efficient management of water resources for effective agriculture, since water is a limited resource and modern agriculture has to face the increasing scarcity of water for irrigation, as a result of the reduced availability and the increasing competition of civil and industrial sectors [29].

Physical Factors: These include climate conditions, geological situations, soil types, hydrological conditions, and all other physical geographic conditions unique to an environment (for example aquifer conditions and underground water levels) that influences how water is used and management for effective agriculture.

Agricultural Factors: As also explained in the literature, these includes irrigations systems and methods, crop section techniques, groundwater levels, use of effective technologies (for example wireless systems) and automotive systems and water body availability.

Socioeconomic Factors: These are factors that influence water management/security for agriculture from a social, economic and political aspect, which is also very critical to develop effective and efficient water management strategies. Such drivers include water policies and laws, population and farmer population distributions, farmer profit, agricultural revenue, market prices (including cost of production using various systems).

Conditional Factors: These are factors that are not directly measured but act as catalysts to water management results and processes for effective farming; and so, must also be understood for more robust effective strategies. Such factors could be farming expertise and processes, fertilizers/chemicals, diversity/inclusion, management strategies and political will.

3.2 Techniques for Effective Water Management in Agriculture

Though while also recognizing that the utilization of technologies and techniques to aid water management and water security for agriculture is only part of the solution; it's very much pertinent to understand these technologies/techniques and the methodical analysis of their impact and how they can be optimized are important for the development of efficient water management activities for effective and productive agricultural practices. From *irrigation technologies*, to *water saving technologies*, *crop specific water saving techniques/technologies*, *ICT based and Wireless technologies*; these are the more common types of important water management technologies that contributes to effective agriculture and aids associated analysis, needed to continually improve or develop even newer technologies that apply new processes and techniques for an even more efficient water management methods for effective agriculture in the context of the ever-growing competition for water, climate change, drought and other forms of demographic, societal and climatic challenges.

For this data-centric research work, emphasis is on using some data analysis, Machine Learning and Wireless technology algorithms and techniques to analyse water management/security processes for effective agriculture and to meet the challenge of how to incorporate innovative technologies and management approaches in decision making and long term water management policy making to increase and optimize agricultural output and processes with lesser resources and maintain environmental sustainability [30].

3.3.1 Hybrid Relay-Cooperative Wireless Sensor Network System

For the hybrid relay-Cooperative system as shown in Figure 3.4, it is a combination of a multi-hop relay system and a two sensor nodes (i.e. source N and cooperating node N_C) cooperative wireless system.

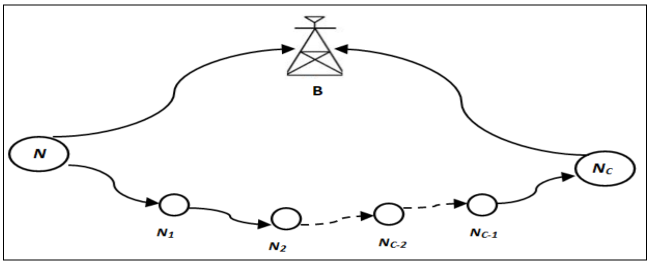

Fig 4: Hybrid Relay-Cooperative Wireless System

In this case as shown in Fig 4, there are relays: N_1, N_2,..., N_{C-1} between the source transmitting sensor N and the 'last relay' which is the cooperative node N_C. This system is suitable for a case where the sensor nodes can access geographical data, and so the cooperating sensor node is selected based on its location, needed to provide effective cooperation to the source sensor node. The sensor nodes between the source node and the cooperating node act as relays (limited intelligence and communication resources) of the signal by forwarding hop by hop the signal from the source to the cooperating sensor node, which then sends the signal to the Base Station (Sink Node) B, where it is combined with the direct signal from the source to the destination, and then the resultant signal is effectively detected by B, thereby benefiting from cooperative communication. The base station then transmits the signal via internet or cellular network to the farmer's mobile devices and intelligent information is received and acted on.

The main ***advantages*** of this system are that it reduces the need for extra hardware and communication resources all around the farm or field, due to the use of less complex relays used to hop signals and a limited number of processing nodes (source and cooperative). This thereby makes the system more cost effective, energy efficient and environment friendly.

The cooperative communications MIMO(Multiple Input-Multiple Output) technique of ***Amplify and Forward (AF)***, which involves each relay and/or cooperative node amplifying the received signal and then forwarding it to the Base Station; while the ***Decode and Forward (DF)*** algorithm involves the relay and/or cooperating nodes in turn tend to detect each node's transmitted data (bits/symbols) and then re-transmitting it to the base station (destination) thereby providing spatial diversity to combat the effect of fading on each individual node's signal.

For the ***Coded Cooperative*** algorithm, which involves more complexity and better performance, it is described in more details as follows:

In the first period: The source node N which is also the node closest to the intended or target area of measurement, sends its data vector X to the first relay node N_1 and the base station B, with the received signals given as $Y_{N,N1}$, $Y_{N,B}$ respectively; and $H_{N,N1}$ and $H_{N,B}$ being the channel co-efficient matrices with their associated Gaussian noise ($n_{N,N1}$ and $n_{N,B}$); as given in equations *(3.9)*and *(3.10)* respectively:

$$Y_{N,N1} = X.H_{N,N1}.\sqrt{P_N} + n_{N,N1} \quad (3.10)$$

$$Y_{N,B} = X.H_{N,B}.\sqrt{P_N} + n_{N,B} \quad (3.11)$$

Also, where P_N is the Average signal power of the source node, which is normalized to 1.

At the second period: Since the relay network is actually a multi-hop system, the first relay node detects the received signal $Y_{N,N1}$ from the source and forwards it to the next relay node N_2 as ($Y_{N1,N2}$):

$$Y_{N1,N2} = Y_{N,N1}.H_{N1,N2} + n_{N1,N2} \quad (3.12)$$

So, from one period to another, the relay nodes keep hoping the signal received from a previous relay node to the next relay node, until the data arrives at the last relay node (i.e., the cooperating node N_C) as:

$$Y_{NC-1,NC} = Y_{NC-2,NC-1}.H_{NC-1,NC} + n_{NC-1,NC} \quad (3.13)$$

Then at the final period, the cooperating node N_C detects and forwards the signal $Y_{NC-1,NC}$ to the Base Station B, as shown in equation *(3.14)*:

$$Y_{NC,B} = Y_{NC-1,NC}.H_{NC,B} + n_{NC,B} \quad (3.14)$$

Then the signal $Y_{NC,B}$ from the cooperating node N_C is then optimally combined with that from the source node $Y_{N,B}$, and then effectively detected.

At each relay node, and also at the cooperating terminal/node N_C, the appropriate cooperative communication technique(e.g., Coded)/protocol is applied to combat the effects of fading, shadowing, thus processing the signal to ensure that the signal can be detected efficiently.

For the **Coded hybrid relay-cooperative system**, at the first period as similarly described; the source/ transmitting node punctures its coded signal N_T (codeword) and sends its first part ***NT1*** to the first relay node N_1, and the base station B. At the second period, the punctured codeword is de-punctured and decoded by the first relay N_1, and then re-encoded, punctured and sent again to the next relay node, N_2. So, the source node's codeword ***NT1*** is de-punctured, decoded and then re-encoded, by each relay node and then punctured and hopped from one relay node to another until the last relay node (the cooperating node N_C); which is assumed to have successfully decoded the $NT1_{NC-1,NC}$ parity bits from the previous relay node N_{C-1} using the Viterbi decoder. Then N_C sends the punctured (second) part $NT2_{NC,B}$ of the source node's codeword to the base station, where the codeword of the source node is de-punctured and then effectively combined.

For a **Coded hybrid relay-cooperative system** with more than one cooperative node (multi-cooperation); MRC is employed first by the base station, to combine all the several versions of the transmitted codeword ***NT2*** from the cooperating nodes, to form one optimal second parity codeword of the source node's signal. Then the base station then carries out the de-puncturing and efficient detection using the hard decision viterbi decoder, in this case also, it must be pointed out that decoding was assumed to be successful at every cooperating user and the base station, thereby the CRC would need not to be implemented.

Table 1: Cooperative Wireless System Parameters

Modulation Scheme	QPSK	**FFT Size for OFDM**	64
Multiple Access Scheme	OFDMA	Cyclic Prefix Size	12
Fading Channel Model & Number of Taps	Rayleigh Frequency selective fading & 13Taps	Data Frame Size	128
Simulation Technique	Monte Carlo	Target Bit Error Rate (BER)	10^{-3}

Wireless System Figures of Merit

- **Bit Error Rate (BER):** The *BER* was used as a measure of the performance of the systems analysed, therefore it is the figure of merit used to achieve one of the targets the Hybrid Cooperative Communication system. The *BER* indicates the probability of bit error P_b, or how many bits are in error for a given transmission, range of available energy, and channel conditions; thereby providing a measure of the quality of data transfer.

Therefore;

$$BER = Ne/Nb \quad (3.15)$$

Where:

Ne is the number of bit errors, and Nb is the number of bits transmitted

- **Signal to Noise Power Ratio (SNR):** In harmony with the second key 'target' of this project work, which is **Energy Efficiency** described in Chapter1 of this thesis; the *SNR* is used as a measure of the energy (processing and transmission) consumed to achieve good quality communication at a target *BER*.

$$SNR\ (dB) = E_b / N_0 \quad (3.16)$$

Where:

E_b is the energy per transmitted bit, and N_0 is the noise spectral density, denoting the noise power

So, in the simulations, the ratio of energy consumed in the transmission of a bit to the noise, provides the particular

SNR or rather energy consumed. Therefore, the ***BER vs E_b /N_0*** curve is a standard in this work for analysing the performance and overall energy consumption of each system model simulated.

Also, another figure of merit relating to energy efficiency is the **Energy Saved**, which is a measure of the overall amount of energy saved (*SNR*) to meet a target *BER* as more processing is done in the system:

$$Overall\ Energy\ Saved\ (dB) = E_P\ (dB) - (dB) \quad (3.17)$$

Where:

E_P is the energy spent in processing, and E_{PER} is the reduced energy spent to achieve the new improved performance

4. Results and Discussion

4.1 Performance (*BER*) Comparison of Cooperative MIMO techniques for the Hybrid Cooperative System

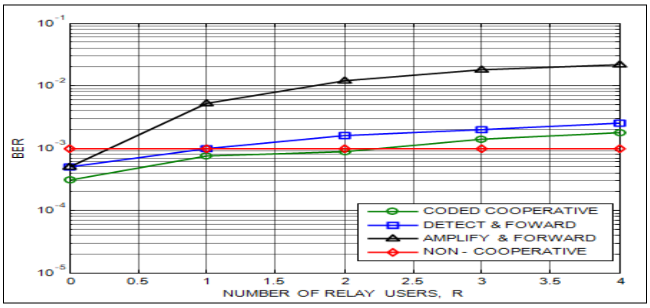

Fig 5: Performance (*BER*) Comparison of Cooperative MIMO techniques for the Hybrid Relay / Cooperative System having *R* Relay nodes, between the source node and cooperating node

4.2 Energy Consumption Comparison of Cooperative MIMO techniques for the Hybrid Cooperative System

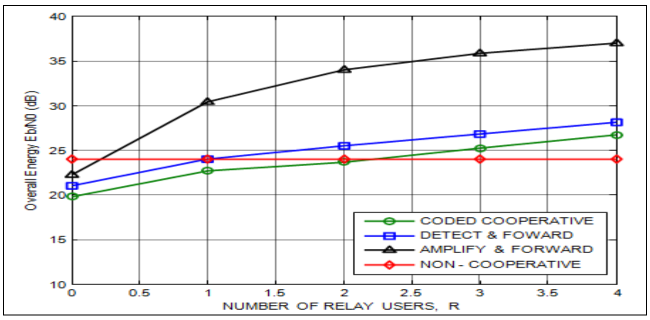

Fig 6: Overall Energy Consumption Comparison of Cooperative MIMO techniques for the Hybrid Relay / Cooperative System having *R* Relay nodes between the source(N) and cooperating node(Nc), where the inter – node and uplink channels have the same mean SNR (E_b /N_0)

As earlier described in the methodology, this Hybrid Cooperative Communication System is designed and analysed to investigate the performance and Energy Consumption of such a system and the output of each of the cooperative MIMO techniques in such a system. Here in Figures 5 and 6, more cooperative communications techniques (***Amplify and Forward (AF)***, ***Decode and Forward (DF)*** and the ***Coded Cooperative System***) and are compared with respect to their Performance and Energy Consumption as against a non-cooperative wireless system. Where the relays nodes (***N_1…N_{c-1}***) and indicated as ***R***, the cooperative node(s) (***Nc***) as ***C***; and the Base/Control sink node or station as ***B.*** For this analysis, he nodes (i.e., Source, Relay and Cooperative) are also 'unpaired', and just one cooperating node (***Nc***) provides cooperation to the transmitting/source node (***N***); while the inter – node and uplink channels have the same mean SNR (E_b /N_0).

As shown in Fig 5; the comparison in performance (*BER*) was made at a fixed SNR (E_b /N_0) of 24dB for the non – cooperative case that gives the target *BER* of 10^{-3}. As shown the cooperative systems show significant decline in performance as the number of relay nodes, increases; this because the multi – hop protocol has the draw – back of loss of data integrity as the links gets longer (reduced end-end reliability), because the data received and then forwarded by a relay would be also contain more noise, thereby reducing performance. For the **Amplify& Forward** and **Detect & Forward** techniques; this is more evident because of their repetitive protocol, for the ***AF***, this is because each relay amplifies the signal received, thereby also amplifying more noise, while for the ***DF***; since each relay forwards the data it receives, so it forwards also erroneous bits, therefore reducing the performance of the system. The ***Coded*** cooperation on the other hand shows a better performance than the other two techniques because of the inherent error correcting ability of the channel code, but as the number of hops gets longer, performance degrades, as the number of erroneous bits can no longer be handled by the code. This again confirms that increased processing, and channel coding gives a boost to cooperation, as coded cooperation benefits from its error correcting ability of its code.

As shown in Fig 6; the comparison in overall (total) energy consumed by cooperation was made with the non – cooperative case at a fixed target *BER* of 10^{-3}. As shown the energy efficiency also reduces as the number of hops increases. This is due to the limitation of the multi – hop system, whereby data integrity reduces as the link gets longer, therefore, making the relay nodes need more energy to maintain link quality, henceforth leading to an overall increase in energy consumption. As shown, the for the **Amplify & Forward** and **Detect & Forward**, show very low energy savings, due to the repetitive nature of their protocols as explained in the performance section above, so as loss of data integrity increases, they would need more energy to maintain a good performance. Furthermore, as shown in Figures 5 and 6; the ***AF*** and ***DF*** algorithms show acceptably good performances and energy savings when the number or relay users are at minimal values. Though small, but on a practically larger scale of many nodes, this incremental savings of energy and performance advantages can also be of very good use; as it has the advantage of lesser coding that accompany the ***coded*** system.

As indicated, the Coded Hybrid cooperative system will give a better performance in terrains where there tends to be signal distortions, which will enable a more intelligent monitoring and management of water resources for effective agricultural processes. As shown, the **coded cooperative** having the advantage of the error correcting ability of the code, is the most energy efficient of the three techniques, though also nor being very energy efficient as the number of relay hops increases, thus the diversity gain and also the coding gain is reduced, as typical of sensor nodes as also confirmed by other research work that simulated output results for the two wireless sensors differed as the number of nodes increased; when there were more nodes, the packet loss ratio increased, and the throughput decreased [31]. So also, this system's performance and energy efficiency reduces as the number of relay hops increases, though the cooperating node tries to improve the performance and energy efficiency.

For the integrated algorithm approach, this extra simplification provided by the ***AF*** and ***DF*** for minimal number of relays and also shorter hops, can be put to use by developing an integrated system that incorporates ***AF*** and ***DF*** schemes for specific hops and then the ***coded*** algorithm for specific longer hops, to ensure that a tradeoff between simplicity and cost is achieved by ensuring the whole network of nodes operates optimally and at minimal energy consumed with the use of different MIMO schemes/techniques at different hops and linkages. Therefore, it can be deduced that the hybrid relay / cooperative system can also be profitable, meeting performance targets and also being energy efficient and environmentally friendly; by ensuring a coded cooperation technique or a technique with channel coding is used, using short relay hops between source(s) and cooperating nodes(s), lesser hardware and power consumption. Channel variations are a major issue in practical wireless systems, and so this makes efficient power control schemes for cooperative communications a key factor of practical importance [32, 33]. Also, the possession of geographical data (as needed in an agricultural setting) would serve well in this case, thereby using the short and even possibly longer relay hops to route the data from the source to the cooperating node via energy efficient routing algorithms, since the position of the best cooperating node as well, as other nodes would be known. As also in previous researches [34], a typical WSN agricultural system as demonstrated can be the implementation of an Irrigation Management System based on WSN, which incorporates a remote monitoring mechanism via a GPRS modem to report soil temperature, soil moisture, WSN link performance and PV power levels. Sensor network and other [35] agricultural techniques might also help them to store and utilize the rain water, increase their crop productivity, reduce the cost for cultivation and make use of real time values instead of depending just on prediction. Furthermore, previous research [36] also proposed a complete agricultural solution for the farmer based on Wireless Sensor Networks and GSM technology. The data acquired about environmental factors of the field is transmitted to the farmer enabling him to control the actuators in the field. As also described by previous research works, the sensor/node data uploaded to the internet using the data logging unit can be accessed from both personal computers (PCs) and mobile phones [10].

4.3 Analysis of the Hybrid Cooperative Wireless System and number of Cooperating Nodes

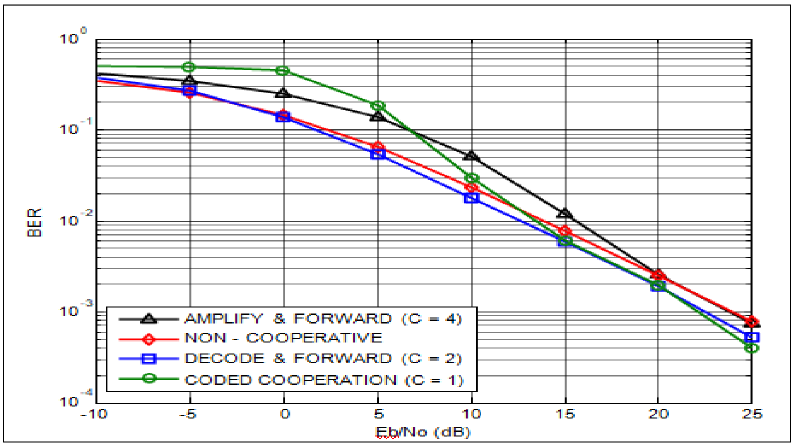

Fig 7: Cooperative MIMO techniques for the Hybrid Relay / Cooperative System and having one Relay, $(N_1 \ldots N_{c-1} = R = 1)$ and number of Cooperating nodes $(N_c = C)$; where the inter – node and uplink channels have the same mean SNR (E_b / N_0)

The Hybrid Cooperative system is analysed as shown in Fig 7, with respect to number of cooperating users, with the intent to investigate how the system Performance and Energy Efficiency varies with respect to each of the cooperative MIMO techniques.

As shown in Fig 7, the nodes are also 'unpaired'; and each cooperative MIMO technique is shown with the amount of cooperating nodes $(N_c = C)$, each technique needs to achieve at least the performance of the non – cooperative case. Also shown by the *BER* values, the **performance** of this system improves as the number of cooperating nodes to the source, and the relay increases; this is so, because as diversity, better signal integrity increases; there would be fewer errors at the receiver(s). Furthermore, the minimum number of cooperating users $(N_c = C)$, in relation to the amount of relay nodes differs with respect to the cooperative MIMO technique, due to each technique's protocol as earlier explained.

Also, as shown in Fig 7 at a target *BER* of 10^{-3}; **energy efficiency** improves for each cooperative technique as the number of cooperating nodes' increases; this as earlier pointed out is due to more processing by more nodes, reduced errors, and more diversity, thereby reducing the overall energy consumption of the system. Furthermore, as management of resources is also a key potential of this system; each technique is shown to require a minimum amount of cooperating users to be added to a minimum amount of relay nodes (one in this case), to provide at least a performance as good as the non – cooperative system, and saving a sizeable amount of energy.

Therefore, from this basic analysis, based on the target BER; the cooperative techniques would require the following least amount of cooperating nodes to meet the set target Performance and Energy threshold:

- Coded cooperation - $N_c = C \geq R$
- Detect & Forward - $N_c = C \geq R + 1$
- Amplify & Forward - $N_c = C \geq R + 3$

Where,

$R = 1$; is the minimum number of relay nodes $[(N_1 \ldots N_{c-1}) = R]$, and $(N_c = C)$ is the minimum number of cooperating nodes.

Also, as shown is that as the number of cooperating users are increased or made larger than the number of relays, the performance and energy efficiency improves for each technique, though each technique would require a unique criterion for the minimum number of cooperating users needed. This hybrid system can also have the potential of providing effective management of resources, because any relay while acting as a multi – hop link between a source and a cooperating user, can simultaneously be a cooperating user to another source, thereby maximizing system resources. Additionally, as a typical WSN wireless network, based on the network connectivity, the power consumed in the network can also be computed or also estimated and then can be predicted. As shown by other research works [37]; WSN nodes have three energy consumptions states: sleep, transmit and receive; but for this research work, the focus here is transmitting/transmission wireless power.

The hybrid relay / cooperative system mitigates loss of data integrity associated with a repetitive multi – hop system (which has also been shown to be less energy efficient as the number of relays became larger than the number of cooperating users for all cooperative MIMO techniques). Additionally, the coded cooperative technique of the Hybrid/Relay cooperative system was shown to be the best in terms of performance and energy efficiency, and for even further improvement of the coded cooperative technique, the use of more robust coding schemes like turbo codes, overlay block – fading codes could be implemented to improve performance [14, 22, 15], over the RCPC codes as used in this research work.

Furthermore, from the comparative analysis results of the three Hybrid/Relay cooperative MIMO techniques; further increased performance and energy efficient cooperative communications could be achieved by using cooperative technique(s) that involve channel coding (maintaining quality signal strength and performance is regardless of the conditions of the wireless channel); pairing between users, appropriate relay assignment scheme(s), and possibly more cooperating users for greater cooperative diversity gain.

5. Limitations and Recommendations of Study

The cooperative hybrid/relay wireless system; the code rate of the RCPC codes can be made more flexible by dividing the frames into more sub frames, and thereby adjusting the sizes of the frames for much improves performance and energy efficiency, especially in a multi –user system [20]. Furthermore, pairing and the issue of partner assignment was not implemented in this work; it is an issue in multi – user systems, and can be effectively implemented by using effective algorithms or schemes that give optimal or near optimal performance by efficient choice of partners in a multi – user environment making the base station able to treat all nodes fairly, based on the knowledge it has of all the channels between nodes.

Also, this work was done on the basis of equal transmit power of wireless sensor nodes; but it can be taken further by implementing an adaptive power control mechanism, that varies as nodes' transmit power based on the instantaneous channel (inter – user and uplink) conditions; in this way much more energy efficiency and improved performance would be achieved. Additionally, as it's also known that the range of battery-operated wireless sensor devices is limited; so, multi-hop communication is also very useful in sending data to control or base station [38].

Tests on the cooperative MIMO techniques can also be done on a variety of environments, which do possess unique channel characteristics; in this way much more developments in the cooperative MIMO techniques as well as improving each techniques' performance with reference to unique wireless environments shall be obtained. This hybrid relay / cooperative system can be further investigated, with energy and performance efficient routing protocols developed, so as to 'unlock' the potentials of this system. This system promises efficient resource management, effective geographically based communications, improved performance and energy efficiency, and other potentials which may not be fully known at this stage.

6. Conclusions

Agriculture is the primary source of income for three out of every four people on the planet who are living in poverty, and it is crucial for food security and economic development in developing countries. Therefore, innovative concerns and measures must be used in agricultural water management and practices for both field and system in order to decrease water scarcity, increase environmental friendliness and societal welfare, and thereby increase food production.

Datasets from trustworthy and recognized data stores, portals, and sources were used for this study's research work, analyses, demonstrations and investigations; as a result, it may be assumed that the datasets are reliable and credible.

Cooperative communications has been shown in this work to improve performance in terms of *BER* and also energy efficiency by saving a good amount of total energy (for similar channel conditions), thereby reducing the overall (total) energy consumption of the system, compared to a non – cooperative system. Therefore, the trade – offs in performance and transmit power is confirmed; because, having more wireless nodes cooperating would mean more processing at each node leading to better performance, though this would arguably mean more node power for processing; but each node would transmit with a reduced energy to maintain network quality, thereby reducing the net energy consumption of a cooperative system. Analysis of the Hybrid/Relay cooperative communications system, showed useful potentials and benefits in terms of performance and energy efficiency and thus is a key technology needed to further improve wireless communications, which will be very useful in the intelligent and technologically driven management of water resources for effective agriculture; by ensuring that useful information on weather, soil, environment, crop, demographics, water sources and water related and irrigation information and data can be accessed, transmitted in real time and used to analyse, monitor, manage and implement timely actions and policies that would further optimize the water agriculture and food nexus for the great good of society.

7. Declarations

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Competing Interest: There is No conflict of interest and none to be declared with respect to this work.

Availability of Data: All data related to this research work are within the manuscript, no extra data outside.

Code Availability: Software used is MATLAB. Codes will be made available, if requested or needed. Thank you.

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