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# ENERGY EFFICIENCY OF MIMO COOPERATIVE NETWORKS WITH ENERGY HARVESTING SENSOR NODES

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## ABSTRACT

*This paper addresses the maximizing network lifetime problem in wireless sensor networks (WSNs) taking into account the total Symbol Error rate (SER) at destination. Therefore, efficient power management is needed for extend network lifetime. Our approach consists to provide the optimal transmission power using the orthogonal multiple access channels between each sensor. In order to deeply study the properties of our approach, firstly, the simple case is considered; the information sensed by the source node passes by a single relay before reaching the destination node. Secondly, global case is studied; the information passes by several relays. We consider, in the previous both cases, that the batteries are non-rechargeable. Thirdly, we spread our work the case where the batteries are rechargeable with unlimited storage capacity. In all three cases, we suppose that Maximum Ratio Combining (MRC) is used as a detector, and Amplify and Forward (AF) as a relaying strategy. Simulation results show the viability of our approach which the network lifetime is extended of more than 70.72%when the batteries are non rechargeable and 100.51% when the batteries are rechargeable in comparison with other traditional method.*

## KEYWORDS

*Energy-Efficiency, MIMO Cooperative, Cooperation Communication, Amplify-and-Forward, Optimal Power Allocation*

## 1. INTRODUCTION

Wireless sensor networks (WSNs) are an important technology that has been employed in various applications. This network type is composed of a large number of sensor nodes distributed on a geographic zone, which can be dropped from an aircraft or helicopter, for tracking physical phenomena (temperature, sound, vibration…..). Each node equipped with an embedded processor, sensors and a radio. Maximizing network lifetime is the most important objective for evolving sensor networks. Network lifetime can be defined according to the used application. In [1] Network lifetime was defined as the time until the first sensor runs out of energy, however in [2] was defined as the time until the last sensor runs out of energy.

In this paper, our goal is to find the optimal transmission power in order to maximize the network lifetime considering different schemes and taking to account the total SER constraint at destination. We assume that source node transmit their obtained sensing data to relaying nodes before reaching the destination virtually creating MIMO system [3]. Concerning the

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mediaaccess, we assume orthogonal channel between each sensor [4]. The channel based on standard strategy of Time Division multiple accesses (TDMA) [5]. The temporal space is divided between all the transmitters.

The remainder of the paper is organized as follows. The section II looks at the related work and background of the approaches and algorithms used. In the section III, we study the maximizing network lifetime problem considering different schemes where the batteries are non-rechargeable. Then, we assume the same assumptions quoted before with the exception that the transmitters are able to harvest energy from nature (rechargeablebatteries). The section VI summarizes our simulation results and the last section concludes the paper.

## 2. RELATED WORK

In wireless Sensor Network (WSN), the most important objective is to make the nodes operational as long as possible. In the literature, there are numerous works that address the network lifetime problem.

Cooperative communication [6][7] is new class method which mitigates the degradation effects of fading channels by exploiting the diversity gain achieved via the relay nodes. Cooperative diversity is realized by different relaying strategies. We mention the most popular strategy namely amplify-and-forward, demodulate-and-forward, Decode-and-Forward and Compress-and-Forward strategy. In the Amplify-and-Forward strategy (AF) [8], the relay simply amplifies the source transmission and retransmits it. The Demodulate-and-Forward strategy [9] permits to the relay to demodulate individual symbols and to retransmit them. In the Decode-and-Forward (DF) strategy [10], the relay decodes the entire message, re-encodes it and re-transmits it to the destination. In [11], the Compress-and-Forward (CF) strategy allows to the relay to send a quantized version of its received signal. The most popular cooperation strategies are amplified-and-forward (AF) and decode-and-forward (DF) [12]. Theoretical studies such as [12] show clearly that the choice of the best strategy is based on Signal-to-Noise Ratio (SNR) of the different channels, and specify that the AF strategy does not to lose information since there is no decision at the relay. From a complexity standpoint, the AF strategy appears to be the simpler of strategies which it used in our work.

Various energy efficient protocols have been proposed to prolong network lifetime. Heinzelman et al. proposed a Low-Energy Adaptive Clustering Hierarchy protocol (LEACH) in [13] which the selection strategy of heads nodes is made randomly. Then, in [14], the authors improve the LEACH protocol [15] and propose an optimized algorithm for the clustering in order to prolong network lifetime.

In [16][17] optimal solutions are presented for maximizing a static network lifetime through a graph theoretic approach using a static (multicast/broadcast) tree. In [18][25], the total energy consumption is minimized using an optimal water-filling solution.

On the other hand, there has been recent research effort on wireless communication using energy harvesting transmitters [19]-[21]. In [19], energy harvesting transmitters with batteries of finite energy storage capacity are considered and the problem of throughput maximization by a deadline is solved in a static channel. Sharma et al. in [20] propose energy management schemes for a single energy harvesting node. The aim is to maximize the throughput and minimize the delay. In [21], the dynamic programming framework is used to calculate the optimal online policy with different energy budgets.

## 3. OPTIMAL POWER ALLOCATION SCHEMES

### 3.1 General System Model

We give a background and precisely define the terms used throughout this paper. We know that the received power at a node varies according to the distance between U-node and V-node noted $d_{uv}^{\alpha}$ , where $\alpha$is the path loss (attenuation) factor. The path loss can be formulated as $L = 10\,\alpha\, log_{10}(d) + Cte$. We assume a source-node, destination-node and $M$ sensors (relays) randomly distributed in the area of interest. We suppose that each sensor has an initial energy noted $E_{int}$ and each one is equipped by only one antenna and has an "Amplify and Forward" as relaying strategy.

We consider the problem of optimal power allocation for WSNs when using the Orthogonal Channel Configuration between each sensor. We Note that $h_{uv}$ is the channel coefficient from the u-node to the v-node assuming that has a Rayleigh distribution and $\varphi_{uv}^2$ represents the well known variance where$\varphi_{uv}^2 = \frac{Cte}{d_{uv}^{\alpha}}$. In addition, $n_{UV}$ is the additive Gaussian noise between U and V node with $n_{uv} \sim \mathcal{N}(0, N_0)$.

In this article, our goal is to maximize the network lifetime expressed by the following equation:

$$L = N \times T$$

Where *T* is the period measurement of channel condition (*T=1* to simplify), *N* is the number of transmissions until the network can continuously meet the application requirements. This is valid for many types of modulation including, quaternary phase shift keying (QPSK), M-pulse amplitude modulation (M-PAM), and rectangular M-quadrature amplitude modulation (M-QAM) [22].

### 3.2 Virtual MIMO with a Single Relay

Firstly, we assume that the source node transmit their obtained sensing data to relaying station before reaching the destination creating several boughs (Fig. 1). We note that exist two communication systems: *SIMOsystem* created between the source-node and the M relay-nodes and *MISO system* created between the M relay-nodes and the destination-node which makes a *virtual MIMO* with a single relay in each bough.

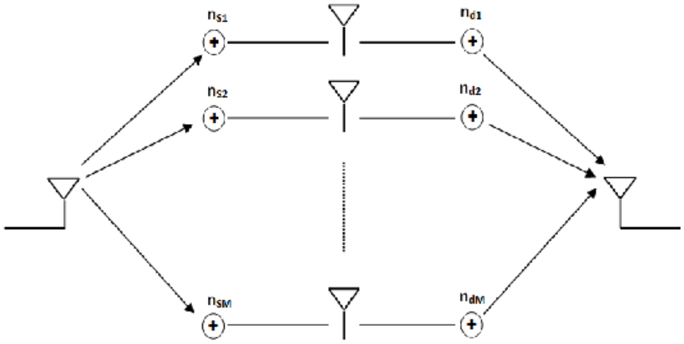

Figure 1: System Model

We consider that the nodes transmit their data over quasi-static rayleigh fading channel. Our aim is to find the optimal power transmission taking into account the required SER at the FC. The average SER at high SNR is formulated as [22][23]:

$$P_e(M) = \frac{C(M,k)}{\bar{\gamma}_{sd}} \prod_{r=1}^{M} \left(\frac{1}{\bar{\gamma}_{sr}} + \frac{1}{\bar{\gamma}_{rd}}\right) \quad (1)$$

Where

$$C(M,k) = \frac{\prod_{j=1}^{M+1} \left[ 2j - 1 / 2(M+1)! \right]}{k^{M+1}}$$

$k$ is a parameter relating to the modulation type used (see Table 1),$\bar{\gamma}_{uv}$ is an average *SNR* of the *u*-node to the *v*-node, where $\bar{\gamma}_{uv} = \varphi_{uv}^2 P_t / N_0$ and $P_t$ is the average transmission power.

In order to simplify our calculation, we start by writing the average SER at the high SNR in terms of transmission power:

$$SER = \frac{C(M,k)}{P_s\varphi_{sd}} \prod_{r=1}^{M} \left(\frac{1}{P_s\varphi_{sr}^2} + \frac{1}{P_r\varphi_{rd}^2}\right) \quad (2)$$

Where $P_s$*(resp.* $P_r$*)* is the power of transmission at the source *(resp.at the $r^{th}$relay)*.

Based on experimental measurements by Raghunathan et al. [24], the data is very expensive in terms of energy consumption. Then the energy consumed in processing and reception is negligible. Consequently, our goal is minimize the transmission power for the *M* relay. We take into account the SER estimation being less than or equal to a known target value δ.

Then, our problem formulation is:

$$\begin{cases} Min \sum_{r=1}^{M} P_r \\ SER \leq \delta \\ P_r \geq 0 \end{cases}$$

We use the method of Lagrange multipliers to find the local maxima of our function, subject to the constraints quoted before. The Lagrange function defined by:

$$£(P_r, \lambda, \nu) = \sum_{r=1}^{M} P_r - \sum_{r=1}^{M} \lambda_r P_r + \nu\left[\frac{C(M,k)}{P_s\varphi_{sd}^2} \prod_{r=1}^{M} \left(\frac{1}{P_s\varphi_{sr}^2} + \frac{1}{P_r\varphi_{rd}^2}\right) - \delta\right]$$

The Karush-Kuhn-Tucker (KKT) conditions are as follows:

$$\begin{cases} \lambda_r \geq 0, \nu \geq 0, \lambda_r P_r = 0 \\ \nu\left[\frac{C(M,k)}{P_s\varphi_{sd}^2} \prod_{r=1}^{M} \left(\frac{1}{P_s\varphi_{sr}^2} + \frac{1}{P_r\varphi_{rd}^2}\right) - \delta\right] = 0 \end{cases}$$

The partial derivative of £ with respect to $p_l$ is as follows:

$$\frac{\partial £(P_r, \lambda, \nu)}{\partial P_l} = 1 - \lambda_l - \nu\left[\frac{C(M,k)}{P_s\varphi_{sd}^2 P_l^2 \varphi_{ld}^2} \prod_{\substack{r=1 \\ r\neq l}}^{M} \left(\frac{1}{P_s\varphi_{sr}^2} + \frac{1}{P_r\varphi_{rd}^2}\right)\right] = 0$$

Then, the solution in term of Lagrangian parameters is as follows:

$$P_l = \sqrt{\frac{\nu}{1-\lambda_l}\left[\frac{C(M,k)}{P_s\varphi_{sd}^2\varphi_{ld}^2} \prod_{\substack{r=1 \\ r\neq l}}^{M} \left(\frac{1}{P_s\varphi_{sr}^2} + \frac{1}{P_r\varphi_{rd}^2}\right)\right]} \quad (3)$$

In the first, we must find the parameters of the Lagrangian. The optimal solution is obtained by solving the KKT conditions: If we consider that$\nu = 0$, using the KKT condition, we obtain that$\lambda_l = 1$, which implies that$P_l = 0 \forall i$. This result is not acceptable, then,$\nu > 0$. If we consider that$\lambda_l \neq 0$, we obtain that$P_l = 0 \forall i$ wich is unacceptable, thus$\lambda_l = 0$. Solving for $P_l > 0$ and $\lambda_l = 0$ from the precedent equation, the Lagrangian parameter $\nu$ can be written as follows:

$$\nu = \frac{1}{\left|\frac{C(M,k)}{P_s\varphi_{sd}^2}\frac{1}{P_l^2\varphi_{ld}^2}\prod_{\substack{r=1\\ r\neq l}}^{M}\left(\frac{1}{P_s\varphi_{sr}^2}+\frac{1}{P_r\varphi_{rd}^2}\right)\right|} \quad (4)$$

In order to find parameters of the Lagrangian, we multiply the previous equation by$\left({1}/{P_s\varphi_{sl}^2} + {1}/{P_l\varphi_{ld}^2}\right)$, we obtain:

$$\nu = \frac{1}{\delta}\left(\frac{P_l^2\varphi_{ld}^2}{P_s\varphi_{sl}^2} + P_l\right) \quad (5)$$

Let us note that $\nu$can be found numerically. Using (5), the solution can be express as follows:

$$P_l = \frac{P_s\varphi_{sl}^2 C(M,k)}{\delta\, P_s^2\varphi_{sl}^2\varphi_{sd}^2\varphi_{ld}^2\left[\prod_{\substack{r=1\\ r\neq l}}^{M}\left(\frac{1}{P_s\varphi_{sr}^2}+\frac{1}{P_r\varphi_{rd}^2}\right)\right]^{-1} - \varphi_{ld}^2 C(M,k)} \quad (6)$$

### 3.3 Single bough with Multi relay (simple case)

Before looking for the case where the information passes through the *N* relays-nodes, in each bough, to reach the destination-node, we take the simple case where it has a one bough. The source-node transmits their obtained sensing data to *N* relays-nodes before reaching the destination which virtually creating MIMO system.

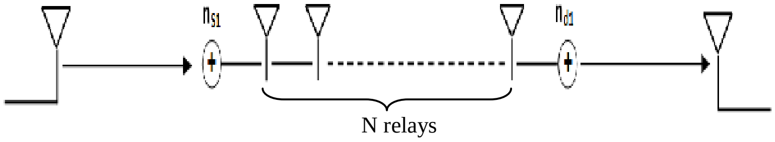

Figure 2: Single bough with a Multi relay

Our aim is to provide the optimal transmission power taking into account the SER constraint at FC while guaranteeing the required performance. Assuming the same assumptions quoted before, the average SER at high SNR is formulated as:

$$P_e(M) = C(M,k)\sum_{i=0}^{N}\frac{1}{\bar{\gamma}_{i,i+1}} \quad (7)$$

Where $C(M,k) = C(1,k) = 3/4k^2$. Then, the average SER in terms of transmission power can be written as:

$$SER = C(1,k)\sum_{i=0}^{N}\frac{1}{P_i\varphi_{i,i+1}^2} \quad (8)$$

Where $P_i$ is the transmission power to the *ith* relay (*i=1,…, N*) and $P_0$ is the transmission power to the source-node. The formulation of our problem can be written as follows:

$$\begin{cases} Min \sum_{i=0}^{N} P_i \\ SER \leq \delta \\ P_i \geq 0 \end{cases}$$

Using the Lagrangian method, we obtain:

$$£(P_i, \lambda, \nu) = \sum_{i=0}^{N} P_i - \sum_{i=0}^{N} \lambda_i P_i + \nu \left| C(1,k) \sum_{i=0}^{N} \frac{1}{P_i \varphi_{i,i+1}^2} \right| \quad (9)$$

The Karush-Kuhn-Tucker (KKT) conditions are as follows:

$$\begin{cases} \lambda_i \geq 0, \nu \geq 0, \lambda_i P_i = 0 \ \forall i \\ \nu \left| C(1,k) \sum_{i=0}^{N} \frac{1}{P_i \varphi_{i,i+1}^2} \right| = 0 \end{cases}$$

The partial derivative of $£$ with respect to $p_l$ is as follows:

$$\frac{\partial £(P_i, \lambda, \nu)}{\partial P_l} = 1 - \lambda_l - \nu \left[ \frac{C(1,k)}{P_l^2 \varphi_{l,l+1}^2} \right] = 0$$

Taking into account the KKT conditions, and following the same lines as in the previous section, we find that $\nu > 0$ and $\lambda_l = 0$. Then, The Lagrangian parameter, after multiplying the both sides by $\varphi_{l,l+1}^2 / C(1,k)$, can be formulated as:

$$\nu \frac{\varphi_{l,l+1}^2}{C(1,k)} = \left( \frac{P_l \varphi_{l,l+1}^2}{C(1,k)} \right)^2$$

After having reversed the equation, we compute the sum of all the resulting equations, we obtain:

$$\nu = \left| \frac{\sqrt{C(1,k)}}{\delta} \sum_{l=0}^{N} \frac{1}{\varphi_{l,l+1}} \right|^2$$

Then, our optimal transmission power can be express as follows:

$$P_l = \frac{C(1,k)}{\delta \varphi_{l,l+1}} \sum_{l=0}^{N} \frac{1}{\varphi_{l,l+1}} \quad (10)$$

### 3.4 Virtual MIMO with a Multi relay (Generalized case)

In this section, we extend the case where multiple relays are used in each bough (Figure 3). We note that three communication systems exists; *SIMOsystem* created between the source-node and first *M* relay-nodes, *SISO system* created between the $N^r$ relay-nodes(*r* denotes the $r^{th}$ bough) and *MISO system* created between the last *M* relay-nodes and the destination-node.

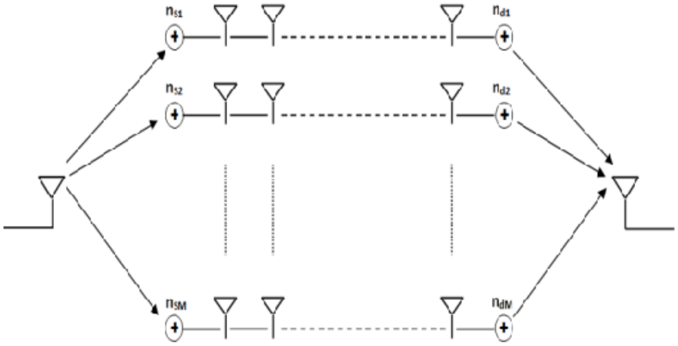

Figure 3: System Model.

The average SER at high SNR, in this case, is formulated as:

$$P_e(M) = \frac{C(M,k)}{\bar{\gamma}_{[s,d]}} \prod_{r=1}^{M} \sum_{i=1}^{N^r} \left(\frac{1}{\bar{\gamma}_{[s,r_1]}} + \frac{1}{\bar{\gamma}_{[r,i]}}\right) \quad (11)$$

Denote that $\bar{\gamma}_{[s,r_1]}$ is the average SNR at the first relay corresponding to the $r^{th}$ bough due to the source-node, and $\bar{\gamma}_{[r,i]}$ is the average SNR of the $i^{th}$ relay corresponding to the $r^{th}$ bough. We consider that we have *M* boughs and each one contains $N^r$ relays (*r* denotes the $r^{th}$ bough). Then, the average SER at the high SNR is expressed in term of power as follows:

$$SER = \frac{C(M,k)}{P_s \varphi_{sd}} \prod_{r=1}^{M} \sum_{i=1}^{N^r} \left(\frac{1}{P_s \varphi^2_{[s,r_1]}} + \frac{1}{P_{[r,i]} \varphi^2_{[r,i]}}\right) \quad (12)$$

Following the same line as the previous section, the formulation of our problem is:

$$\begin{cases} Min \sum_{r=1}^{M} \sum_{i=1}^{N^r} P_{[r,i]} \\ SER \le \delta \\ P_r \ge 0 \end{cases}$$

Using the Lagrangian method, we obtain:

$$£(P_{[r,i]}, \lambda, \nu) = \sum_{r=1}^{M} \sum_{i=1}^{N^r} P_{[r,i]} - \lambda_{[r,i]} \left(\sum_{r=1}^{M} \sum_{i=1}^{N^r} P_{[r,i]}\right) + \nu_{[r,i]} \left[\frac{C(M,k)}{P_s \varphi^2_{sd}} \prod_{r=1}^{M} \sum_{i=1}^{N^r} \left(\frac{1}{P_s \varphi^2_{[s,r_1]}} \frac{1}{P_{[r,i]} \varphi^2_{[r,i]}}\right) - \delta\right]$$

The Karush-Kuhn-Tucker (KKT) conditions are as follows:

$$\begin{cases} \lambda_{[r,i]} \ge 0, \nu_{[r,i]} \ge 0, \lambda_{[r,i]} \left(\sum_{r=1}^{M} \sum_{i=1}^{N^r} P_{[r,i]}\right) = 0 \\ \nu_{[r,i]} \left[\frac{C(M,k)}{P_s \varphi^2_{sd}} \prod_{r=1}^{M} \sum_{i=1}^{N^r} \left(\frac{1}{P_s \varphi^2_{[s,r_1]}} + \frac{1}{P_{[r,i]} \varphi^2_{[r,i]}}\right) - \delta\right] = 0 \end{cases}$$

The partial derivative of £ with respect to $P_{[l,j]}$ is as follows:

$$\frac{\partial £(P_{[r,i]}, \lambda, \nu)}{\partial P_{[l,j]}} = 1 - \lambda_{[l,j]}$$

$$- \nu_{[l,j]} \left[ \frac{C(M,k)}{P_s \varphi_{sd}^2} \frac{1}{P^2{}_{[l,j]} \varphi_{[l,j]}^2} \sum_{\substack{r=1 \\ r \neq l}}^{M} \left( \sum_{i=1}^{N^r} \left[ \frac{1}{P_s \varphi_{[s,r_1]}^2} + \frac{1}{P_{[r,i]} \varphi_{[r,i]}^2} \right] \right) \right] \quad (13)$$

Following the same instructions quoted before, we obtains that $\nu_{[l,j]} > 0$ and $\lambda_{[l,j]} = 0$. In order to find the optimal solution, we must start by finding the Lagrangian parameters. According to the previous equation, we have:

$$\nu_{[l,j]} = \frac{1}{\left[ \frac{C(M,k)}{P_s \varphi_{sd}^2} \frac{1}{P^2{}_{[l,j]} \varphi_{[l,j]}^2} \sum_{\substack{r=1 \\ r \neq l}}^{M} \left( \sum_{i=1}^{N^r} \left[ \frac{1}{P_s \varphi_{[s,r_1]}^2} + \frac{1}{P_{[r,i]} \varphi_{[r,i]}^2} \right] \right) \right]} \quad (14)$$

We multiply the (13) by $\sum_{i=1}^{N^r} \left[ \frac{1}{P_s \varphi_{[s,l_1]}^2} + \frac{1}{P_{[l,i]} \varphi_{[l,i]}^2} \right]$, we obtain:

$$\nu_{[l,j]} = \frac{P^2{}_{[l,j]} \varphi_{[l,j]}^2}{\delta} \left[ \sum_{i=1}^{N^r} \left[ \frac{1}{P_s \varphi_{[s,r_1]}^2} + \frac{1}{P_{[l,i]} \varphi_{[l,i]}^2} \right] \right]$$

Let us note that $\nu$ can be found numerically. Finally, the optimal transmission power for the node in the $l^{th}$ bough and $j^{th}$hop is given by:

$$P_{[l,j]} = [\varphi_{[l,j]}]^{-1} \sqrt{\frac{\delta \nu_{[l,j]}}{\sum_{i=1}^{N^r} \left[ \frac{1}{P_s \varphi_{[s,r_1]}^2} + \frac{1}{P_{[l,i]} \varphi_{[l,i]}^2} \right]}} \quad (15)$$

### 3.5 Energy harvesting in Virtual MIMO with a Single relay

Our goal is to maximize the network lifetime. In this section, we consider the same case in the first part (single relay in each bough), with the exception that the transmitters are able to harvest energy from nature. Figure 4 shows that the transmitter has an energy queue (battery) where the arriving (harvested) energy is stored.In addition, we consider that the energy harvesting times and energy harvesting amount are known before the transmission starts.

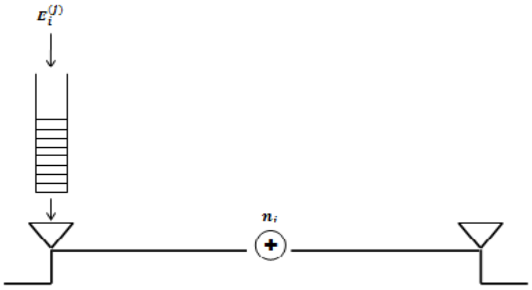

Figure 4: System Model

Noted that $E_r^{(j)}$ is the energy arrivals at *jth* period for the *rth* sensor and $E_r^{(0)}$ is the unit of energy is available at time 0. $h_r^{(j)}$is the fading channel coefficients for the *rth* sensor at *jth* period where j=1,…..,N and r= 1,……, M. For simplify, we note that epoch $T^{(j)}$is time interval between the two previous consecutive events.

Assuming that the transmission power is constant in each epoch $T^{(j)}$, the constraint of causality on the power management policy can be formulated as:

$$\sum_{j=1}^{l} T^{(j)} P_r^{(j)} \leq \sum_{j=0}^{l-1} E_r^{(j)} \qquad (16)$$

Where $P_r^{(j)}$ is the transmission power at the *jth* period for the *rth*sensor.

Our aim is to provide an optimal transmission power in order to maximize the network lifetime taking into account a Symbol Error Rate (SER) constraint and a causality constraint on the harvested energy. We consider that the battery capacity is unlimited ($E_{max} = \infty$ ).

Then, the formulation of our problem is:

$$\begin{cases} Min \sum_{r=1}^{M} \sum_{j=1}^{N} P_r^{(j)} \\ S.t \ \dfrac{C(M,k)}{P_s{}^{(j)} \varphi_{sd}^{(j)^2}} \prod_{r=1}^{M} \left( \dfrac{1}{P_s{}^{(j)} \varphi_{sr}^{(j)^2}} + \dfrac{1}{P_r{}^{(j)} \varphi_{rd}^{(j)^2}} \right) \geq \gamma \quad j = 1, \dots, N \\ P_r^{(j)} \geq 0 \quad \forall j, r \\ \sum_{j=1}^{l} T^{(j)} P_r{}^{(j)} \leq \sum_{j=0}^{l-1} E_r^{(j)} \quad l = 1, \dots, N \end{cases}$$

Using the Lagrangian method, we obtain:

$$£(P, \lambda, \nu, \beta) = \sum_{r=1}^{M} \sum_{j=1}^{N} P_r^{(j)} - \sum_{r=1}^{M} \sum_{j=1}^{N} \lambda_r P_r^{(j)} + \nu \left[ \frac{C(M,k)}{P_s{}^{(j)} \varphi_{sd}^{(j)^2}} \prod_{r=1}^{M} \left( \frac{1}{P_s{}^{(j)} \varphi_{sr}^{(j)^2}} + \frac{1}{P_r{}^{(j)} \varphi_{rd}^{(j)^2}} \right) - \delta \right] + \sum_{r=1}^{M} \sum_{l=1}^{N} \beta_r^{(l)} \left( \sum_{j=1}^{l} T_r^{(j)} P_r^{(j)} - \sum_{j=0}^{l-1} E_r^{(j)} \right)$$

Since the objective function and the constraints are convex, $£$ has a unique maximizer. Using the Karush-Kuhn-Tucker (KKT) condition, we obtain:

$$\frac{\partial £(P, \lambda, \nu, \beta)}{\partial P_i^{(k)}} = 1 - \lambda_i - \nu \left| \frac{C(M,k)}{P_s{}^{(k)} \varphi_{sd}^{(k)^2} \left(P_i^{(k)}\right)^2 \varphi_{id}^{(k)^2}} \prod_{\substack{r=1 \\ r \neq i}}^{M} \left( \frac{1}{P_s{}^{(k)} \varphi_{sr}^{(k)^2}} + \frac{1}{P_r{}^{(k)} \varphi_{rd}^{(k)^2}} \right) \right| + \sum_{l=k}^{N} \beta_i^{(l)} = 0$$

Satisfying the KKT condition, we obtain: $\lambda_i = 0$, then,

$$\nu = \frac{\sum_{l=k}^{N} \beta_i^{(l)}}{\left| \frac{C(M,k)}{P_s{}^{(k)} \varphi_{sd}^{(k)^2} \left(P_i^{(k)}\right)^2 \varphi_{id}^{(k)^2}} \prod_{\substack{r=1 \\ r \neq i}}^{M} \left( \frac{1}{P_s{}^{(k)} \varphi_{sr}^{(k)^2}} + \frac{1}{P_r{}^{(k)} \varphi_{rd}^{(k)^2}} \right) \right|}$$

We multiply the numerator and denominator by $\left( \frac{1}{P_s{}^{(k)} \varphi_{si}^{(k)^2}} + \frac{1}{P_i{}^{(k)} \varphi_{id}^{(k)^2}} \right)$, then, we obtain:

$$\nu = \frac{\sum_{l=k}^{N} \beta_i^{(l)} T_i^{(l)} P_i^{(l)}}{SER} \left( \frac{\left(P_i^{(k)}\right)^2 \varphi_{id}^{(k)2}}{P_s^{(k)} \varphi_{si}^{(k)2}} + P_i^{(k)} \right] \quad (17)$$

Let us note that $\nu$cannot be found easily, that why we assume a solution geometrical. In solution geometrical we can present all target solutions in a region in which all the constraints are satisfied.

The figure 9 shows the feasible region where all feasible solutions must lie in. The figure has upper wall which presents the cumulative energy harvested$\sum_{j=0}^{l-1} E_i^{(j)}$. In other hand, this wall presents the total emission energy that can be spent. The required power consumption $P_i^{\square}$ must be full located inside this region. In our algorithm, we use the equation (6) to calculate the optimal power ensuring that this power is not greater to $p_{max_i}^{(l)}$ where

$$p_{max_i}^{(l)} = \frac{\sum_{j=0}^{l-1} E_i^{(j)}}{T_i^{(l)}} \quad (18)$$

We recalculate our optimal power once a new energy amount arrives, or if there is a change in channels status in order to be adapted to these changes. To simplify, we consider that the conditions of channel are measured every one second ($T_i^{(l+1)} - T_i^{(l)} = 1s$ □$i, l$) (see algorithm 1).

***Algorithm 1***

```
INITIALIZATION
$T_i$ ← 0
$P_{opt_i}^{(T_i)}$ ← Find (equ.6)    for i={1,…,M}
START
$T_i$ ← $T_i$++
$p_{max_i}^{(T_i)}$ ← Find (equ. 18)
If $h_i^{(T_i)} \neq h_i^{(T_i-1)}$
$P_{opt_i}^{(T_i)}$ ← Find (equ.6)
If $E_i^{(T_i)} \neq 0$
$P_{opt_i}^{(T_i)}$ ← Find (equ.6)
        If $P_{opt_i}^{(T_i)} \geq p_{max_i}^{(T_i)}$
$P_{opt_i}^{(T_i)}$ ← 0    (don't transmit)
END
```

## 4. SIMULATIONS AND RESULTS

We study the average network lifetime. We compare our novel method to EP method when varying same parameters, in order to show the relevance and the robustness of our proposal. The simulations parameters are generated randomly such that each parameter $p$ belongs to an uniform distribution between $\psi$and$\varphi$, $p$ □ $U[\psi; \varphi]$.

### 4.1 Virtual MIMO with a Single Relay

In order to show the viability and the performance of the novel algorithms, we compare it to the equal power method (EP) [25]. We fixed the transmission power corresponding to the source node for 10dB and we vary the modulation of the transmit information. The modulations used are M-Phase Shift Keying (M-PSK) and M-Quadrature Amplitude Modulation (M-QAM), then, the k parameter can be formulated differently in each modulation case (table 1). We suppose that the direct link between the source and the destination node is assumed normalized by 1. We considerer four significant figures where all of the digits present are non-zero.

**Table 1:** Modulation parameters

| Modulation | k |
|---|---|
| M-PSK | $2\sin^2(\pi/M)$ |
| M-QAM | $3/_{M-1}$ |

Figure 5 depicts the lifetime network while increasing the number of boughs. The curves show that the network lifetime is clearly extended when the number of bough exceeds 5. While between 1 and 5 bough, the improvement is less important in terms of network lifetime. In general, the proposed approach improves the EP method concerning the average network lifetime which is extended by an average of 78.01% respectively 70.85%) using 16QAM (respectively 8PSK). Table 2 shows the parameters used for simulations.

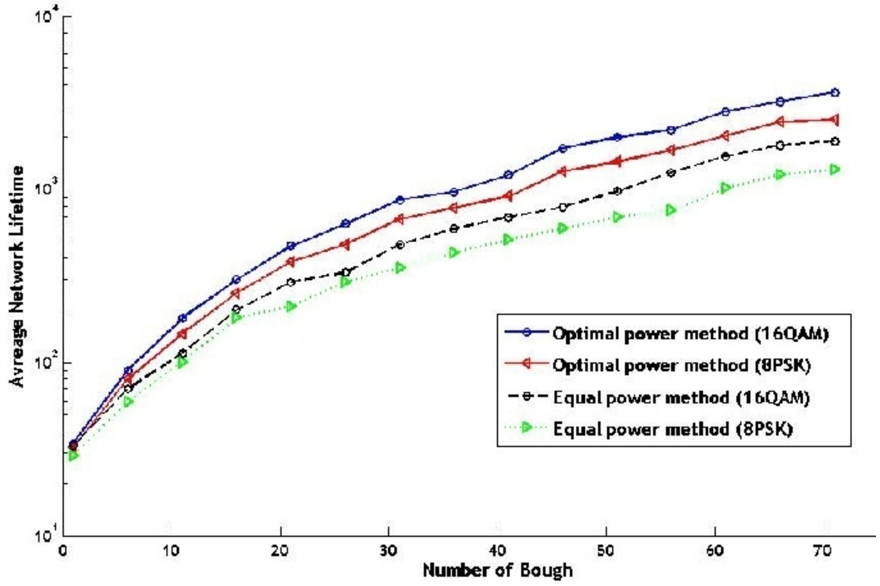

Figure 5: Comparison between the optimal power and equal power allocation.

In the second, we fixed the used modulation (16QAM) and we vary the transmission power corresponding to the source.

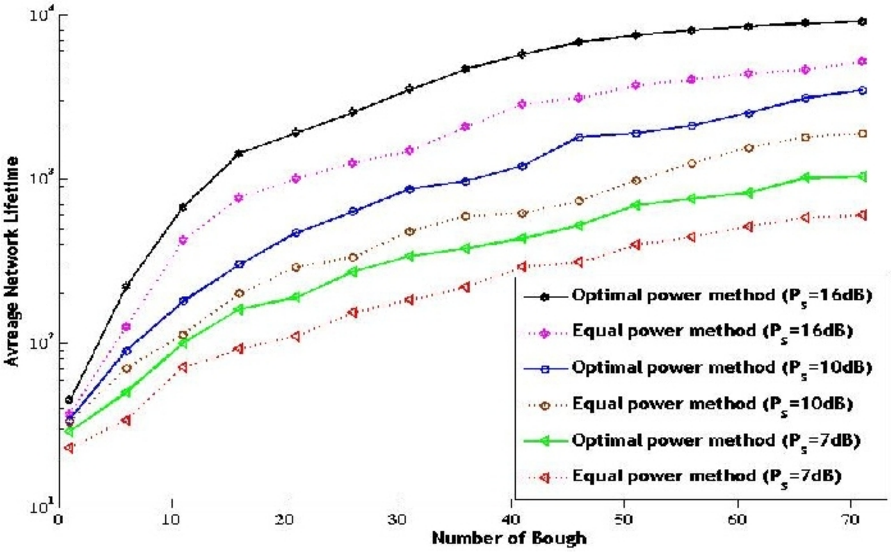

Figure 6: Comparison between the optimal power and equal power allocation.

Figure 6 shows the average network lifetime increasing the number of bough where varying the transmission power corresponding to the source $P_S$. As it can be seen, the network lifetime, in the both methods, increases as the value of $P_S$. However, the curves show that our approach provides a meaningful improvement relative to the EP Method which the lifetime network is extended by an average of 92.23%, 70.72% and 64.31% respectively for $P_S$= 16db, 10db and 7db. Therefore, the simulation results prove that the transmission power $P_S$ and the modulation used play a significant factor in extending the network lifetime. Obviously, with high $P_S$ we can reach farther relay of the source.

**Table 2:**Simulations parameters

| **Estimate** | **Parameters** |
|---|---|
| $10^{-4}$ | $\delta$: The threshold of SER |
| 10dB | $P_S$: Power corresponding to the source node |
| U[0.5,1] | $d_{uv}^2$ Distance between u and v node ($\alpha$ = 2) |
| U[100, 400] | $E_{int}$:The initial energy |

## 4.2 Virtual MIMO with a Multi relay

Figure 7 represents the average network lifetime while increasing the number of relays $N$ in each bough $(N = N^r \, r)$. The figure shows that our new method is more effective than the EP method concerning the average network lifetime which is extended by an average of 80.98%. We assume the same Simulations parameters (see Table 3).

**Table 3:**Simulations parameters

| **Estimate** | **Parameters** |
|---|---|
| $10^{-4}$ | $\delta$: The threshold of SER |
| 10dB | $P_S$: Power corresponding to the source node |
| U[0.5,1] | $d_{uv}^2$ Distance between u and v node ($\alpha$ = 2) |
| U[100, 400] | $E_{int}$:The initial energy |

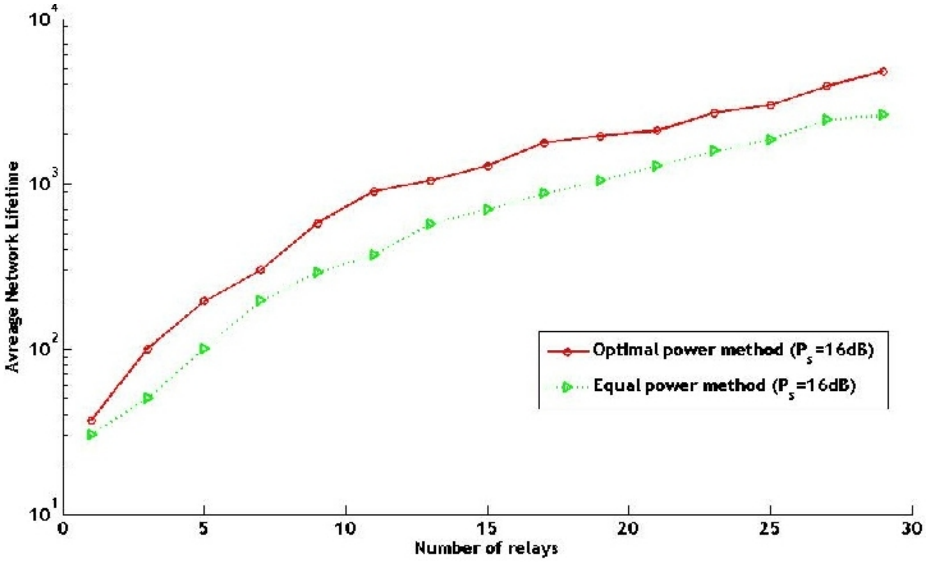

Figure 7: Comparison between the optimal power and equal power allocation.

### 4.3 Energy harvesting in Virtual MIMO with a Single relay

To evaluate the performance of our new algorithm, we compare our Optimal Power Allocation algorithm where the batteries are Rechargeable (OPAR) with two other methods, namely the Equal Power (EP) method and Optimal Power Allocation where the batteries are Non-Rechargeable (OPANR). We assume an unlimited battery capacity, and generate the Quantity of energy arrivals with a Gaussian distribution [50, 100].The 16-QAM modulation is used. Table 4 shows the parameters used for simulations.

**Table 4:**Simulations parameters

| **Estimate** | **Parameters** |
|---|---|
| $10^{-4}$ | $\delta$: The threshold of SER |
| 10dB | $P_s$: Power corresponding to the source node |
| U[0.5,1] | $d_{uv}^{2}$ Distance between u and v node ($\alpha$ = 2) |
| U[100, 400] | $E_{int}$:The initial energy |
| U[50, 100] | Quantity of energy arrivals |

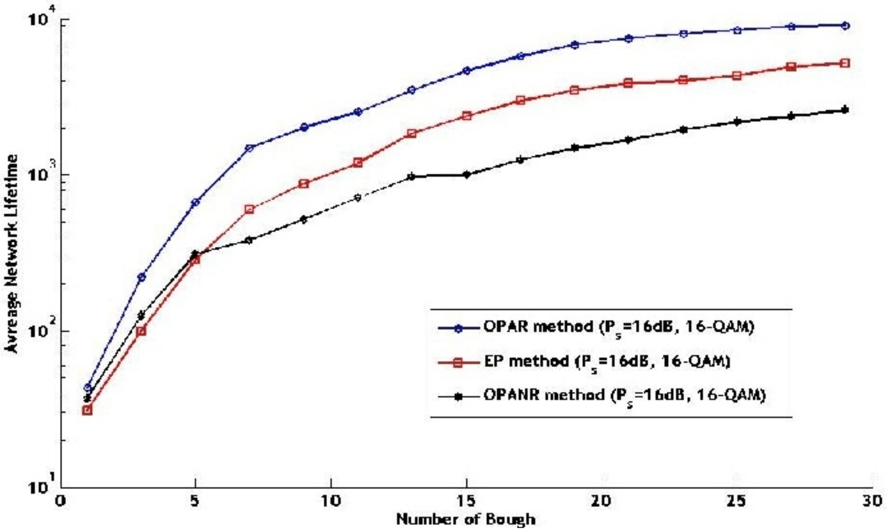

Figure 8: Comparison between the optimal power and equal power allocation.

Figure 8 shows the network lifetime increasing the number of relays. As it can be seen, our proposed OPAR algorithm improves the EP and OPANR method concerning the average network lifetime. For the range [1,9], the improvement is less important in terms of network lifetime. As expected, for more than 9 boughs, the total average lifetime is substantially increased to about 100.51% and 247.78% using OPAR method compared to respectively EP and OPANR method. Table 4 shows the parameters used for simulations.

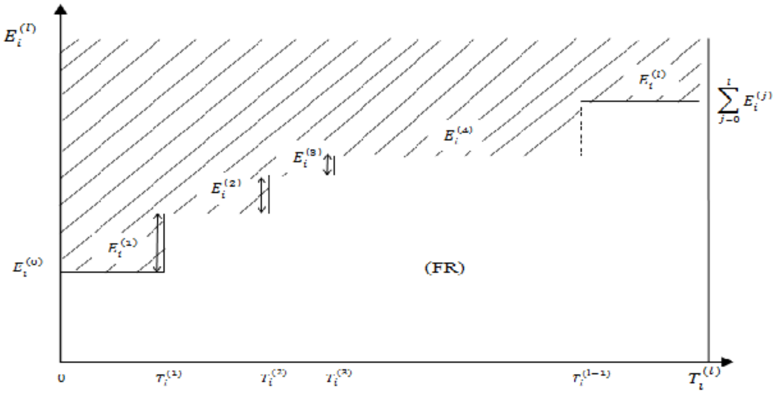

Figure 9: Feasible Region.

## 5. Conclusion

This paper presents a new algorithm which aims to maximize the network lifetime under Orthogonal Channel configuration using several cases. We take into account the estimation of overall Symbol Error Rate(SER) constraint at the FC and we suppose, in addition, that a MaximumRatio Combining(MRC) is used at the receiver as a detector and amplify-and-forward as relaying strategy. We have showed that the proposed optimal power allocation methods maximize the average network lifetime better than the EP method in all the studied cases. The network lifetime is extended by an average that can reach 100.51% when the batteries are rechargeable.

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