Throughput maximization for a wireless energy harvesting node considering the circuitry power consumption

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***Abstract*—The autonomy of wireless nodes is dropping year after year as the battery capacity increase is not able to follow the increasing energy consumption of the nodes, which is produced due to the high demand of data traffic and transmitter processing complexity of the users. Energy harvesting and energy efficient communications, e.g., energy efficient network topologies, are promising solutions to overcome this problem. In this context, this paper studies the power allocation and slot selection strategies that maximize the total throughput of a wireless energy harvesting node by taking into account both the transmission power and circuitry power consumption spent along the radio frequency chain of the transmitter.**

I. Introduction

Energy harvesting, i.e., the process by which energy of different kinds (e.g. light, temperature, wind, electromagnetic, etc.) is collected from the environment and converted into usable electric power, allows to recharge batteries of autonomous devices and, hence, increase their lifetimes. Energy harvesting is specially crucial to power sensor nodes placed in remote places where the replacement of the node battery is a difficult task. Energy harvesting is also essential for devices with high traffic demand and energy availability limitations, e.g., handheld devices. In this context, the research in optimal transmission strategies for Wireless Energy Harvesting Nodes (WEHNs) has greatly increased during last years as the well-known water-filling strategy [1] is no-longer optimal due to the presence of energy harvesters that impose a set of Energy Causality Constraints (ECCs).

A point-to-point communication with an energy harvesting transmitter is considered in [2]–[6]. In these works, the energy harvesting process is modeled as a set of energy packets arriving to the node at different time instants and with different amounts of energy. In many of these works, an *offline* approach is considered, where the amount and arrival time of each energy packet are assumed to be known. In [5] and [6], the authors find the power allocation strategy, referred to as *staircase* or *Directional Water-Filling (DWF)*, respectively, that maximizes throughput by a deadline[1]:

$$P_i = \left(W_i - \tfrac{1}{h_i}\right)^+, \qquad (1)$$

where i is the index that denotes each of the time slots, h_i is the channel gain and W_i denotes the water level that remains constant in the time slots contained between energy arrivals, which we refer to as a *pool*. The main difference between (1) and the traditional waterfilling [1], is that for WEHNs the water level depends on the pool under consideration instead of being constant throughout all transmission.

The previous result follows from assuming that transmission power is the only source of energy consumption in the node. This is a reasonable assumption when the link transmission distance is large as the transmission power consumption dominates over the other sources of energy consumption. However, when energy efficient network topologies are considered, the transmission distances may be below 10 m and the circuitry energy consumption caused by the different components of the radio frequency chain of the transmitter become relevant, even dominating over the transmission power [7], [8].

The impact of the circuitry energy consumption in the capacity of wireless channels is studied in [9], where it is shown that bursty transmission is capacity achieving. In other words, it is preferable to transmit information just during a fraction of the total available time and turn off the device during the remaining time.

To the best of our knowledge, the impact of circuitry power consumption in the power allocation strategy that maximizes the total throughput of a wireless node with energy harvesting capabilities has not been studied in the literature. In this context, this paper derives the optimal power allocation to the aforementioned problem and three suboptimal algorithms that reduce the computational burden of determining the solution.

II. System Model

We consider a point-to-point communication through an Additive White Gaussian Noise (AWGN) channel where the transmitter is a WEHN. The goal of this paper is to design the power allocation strategy along N independent time slots such that the sum rate is maximized by taking into account the availability of energy in the node, as well as, a fixed and constant cost of sending data, i.e., the circuitry power consumption.

Let y_i be the i-th channel output, $i = 1 \ldots N$, i.e., $y_i = \sqrt{P_i} g_i x_i + n_i$, where x_i are the zero mean complex Gaussian distributed input symbols with $E\{|x_i|^2\} = 1$, P_i is the transmission power, g_i is the complex channel response

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[1]**Notation:** Vectors are denoted by lower case bold letters. $[\mathbf{v}]_i$ denotes the i-th component of the vector $\mathbf{v}$, $(x)^+ = \max\{0, x\}$.

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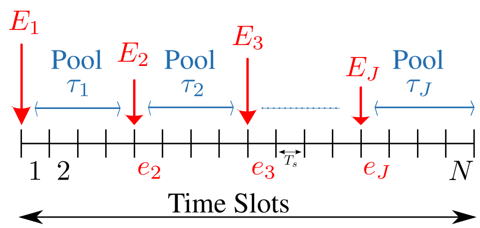

Figure 1. Temporal representation of energy arrivals.

with $h_i = |g_i|^2 \in [0, 1]$ being the channel power gain that models the path-loss, and $n_i \sim CN(0, \sigma^2)$ is the zero mean complex Gaussian noise observed at the receiver. Without loss of generality, we assume $\sigma^2 = 1$. We consider a slow-fading channel where the coherence time of the channel T_C is much larger than the symbol duration T_s, i.e., $T_s << T_C$. Therefore, a constant channel gain is observed through the symbol transmission time. Full Channel State Information (CSI) is assumed at the transmitter.

The energy harvesting process in the transmitter is characterized by a packetized model, i.e., the node is able to collect a packet of energy containing E_j Joules at the beginning of the e_j-th time slot[2] for some $e_j \in [1, N]$. Let J be the total number of packets harvested during the N time slots. The initial battery of the node E_1 is modeled as the first harvested packet, thus, $e_1 = 1$. The amount of energy contained in the packets and the arrival times are assumed to be known, hence, an *offline* approach is considered. We use the term *pool* τ_j, $j = 1 \dots J$, to denote the set of time slots between two energy arrivals, i.e., $\tau_j = \{e_j, e_j + 1, \dots, e_{j+1} - 1\}$[3]. A temporal representation is given in Figure 1.

As in [8] and [9], we consider a constant and fixed circuitry power consumption P_c of transmitting data in a certain time slot that models the power consumed by the different circuit blocks along the signal path (see [8] for more details). Let ρ_i be the power indicator variable, i.e.,

$$\rho_i = \begin{cases} 1 & \text{if } P_i > 0, \\ 0 & \text{if } P_i = 0. \end{cases} \tag{2}$$

The total power consumption at the i-th time slot is $P_i + P_c\rho_i$. Consequently, the sum-rate maximization problem can be formulated as

$$\max_{\{\rho_i\}_1^N, \{P_i\}_1^N} \quad \sum_{i=1}^{N} \rho_i \log(1 + h_i P_i) \tag{3a}$$

subject to

$$\sum_{i=1}^{\ell} P_i + \rho_i P_C \leq E_H(\ell)/T_s, \qquad \ell = 1 \dots N, \tag{3b}$$

where $E_H(\ell) = \sum_{j=1}^{J} E_j H(\ell - e_j)$ is the harvested energy up to the beginning of the ℓ-th slot ($H(\cdot)$ is the Heaviside function with $H(0) = 1$). The domains of P_i and ρ_i are $[0, \infty)$ and $\{0, 1\}$, respectively. The ECCs in (3b) impose that the sum of all the expended energy by the end of the ℓ-th time slot must be smaller or equal that the total harvested energy at the beginning of the slot. Throughout the paper, $i \in [1, N]$ is the time slot index and $j \in [1, J]$ is the pool index.

[2]We assume that the transmitter can only change its transmission strategy in a time slot basis. Based on this, if an energy packet arrives in the middle of a time slot, we can assume that the packet becomes available for the transmitter at the beginning of the following slot.

[3]Note that $e_{J+1} = N + 1$ so that the last pool is well defined.

Note that the problem in (3) is not convex as the domain of ρ_i is not a convex set, indeed, (3) is a mixed binary integer programming problem. Due to the complexity of solving (3), we first study two simplified scenarios from which we obtain two different upper bounds to the optimal solution to (3). First, a static channel is considered in Section III. The second scenario, which is studied in Section IV, considers a node without energy harvesting capability in a slow-fading environment. Finally, (3) is solved in Section V.

III. Static Channel with Energy Harvesting

In this section, we consider a static channel, i.e., the channel gain remains constant throughout the N time slots, $h_i = h$, $\forall i$. Consequently, the problem is

$$\max_{\{\rho_i\}_1^N, \{P_i\}_1^N} \quad \sum_{i=1}^{N} \rho_i \log(1 + hP_i) \tag{4}$$

subject to (3b).

Let N_A be the total number of active channels, i.e., $N_A = \sum_i \rho_i$. Let $\mathbf{s}_{N_A}$ be some slot selection of N_A active channels, i.e., $\mathbf{s}_{N_A} = \{i | \rho_i = 1\}$. Note that, given a certain N_A, there are $\binom{N}{N_A}$ possible slot selections. The following lemma, derives the optimal slot selection when a static channel is considered.

Lemma 1. *Given a certain number of active slots N_A, the optimal slot selection is to transmit through the last N_A time slots, i.e.,* $\mathbf{s}^\star_{N_A} = \{N - N_A + 1, N - N_A + 2, \dots, N\}$.

By applying Lemma 1, Problem (4) is reduced to

$$\max_{N_A} \quad \max_{\{P_i\}_{N-N_A+1}^N} \quad \sum_{i=N-N_A+1}^{N} \log(1 + hP_i) \tag{5a}$$

subject to

$$\sum_{i=N-N_A+1}^{\ell} P_i \leq E_H(\ell)/T_s - (\ell - N + N_A)P_c, \quad \ell \in [N - N_A + 1, N],$$

where the inner optimization problem, which determines the optimal power allocation in some $\mathbf{s}_{N_A}$, is convex and its solution is given by the DWF in (1) [6]. Thus,

$$P_i = \begin{cases} 0 & \text{if } i \in [1, N - N_A], \\ \left(W_i - \dfrac{1}{h}\right) > 0 & \text{if } i \in [N - N_A + 1, N], \end{cases} \tag{6}$$

where W_i are the different water levels obtained through the DWF algorithm. In summary, the optimal solution to (4) can be found by performing an exhaustive search over N_A and computing a DWF at every iteration.

Remark 1. In this section, we have seen that the complexity of solving (3) is greatly reduced when the channel is static. Observe that if h is fixed to the maximum of the observed channel gains throughout the N time slots of problem (3), i.e., $h = \max\{h_i\}$, then, for this value of h, the optimal value of the objective function in (4) upper bounds the optimal value of the objective function in (3).

IV. FADING CHANNEL WITHOUT ENERGY HARVESTING

In this section, we derive the optimal solution to (3) when the transmitter node is not able to harvest energy, in other words, the only energy available is the energy initially contained in the battery, β. Therefore, the goal of this section is to solve the following optimization problem:

$$\max_{\{\rho_i\}_1^N,\{P_i\}_1^N} \quad \sum_{i=1}^{N} \rho_i \log(1+h_iP_i) \tag{7a}$$

$$s.t. \quad \sum_{i=1}^{N} P_i+\rho_iP_c \leq \beta/T_s. \tag{7b}$$

Note that only the last constraint of (3b) ($\ell = N$) is taken into account as it is the most restrictive one. Let the vector $\mathbf{d}$ of dimensions $1\times N$ be the indexing that sorts the channel gains in decreasing order, i.e., $h_{[\mathbf{d}]_1} \geq h_{[\mathbf{d}]_2} \geq \cdots \geq h_{[\mathbf{d}]_N}$.

Lemma 2. *Given a certain number of active slots N_A, the best slot selection is to transmit through the N_A slots with higher channel gain, i.e., $\mathbf{s}_{N_A} = \{[\mathbf{d}]_1, [\mathbf{d}]_2, \ldots, [\mathbf{d}]_{N_A}\}$.*

The previous lemma states that for a fixed N_A, the slot selection is straightforward, the time slots with higher channel gain are selected. In addition, once the slot selection is known, the power allocation in these slots is given by the waterfilling solution [1] with a total power constraint of $\frac{\beta}{T_s} - N_AP_c$, i.e.,

$$P_{[\mathbf{d}]_i}(N_A) = \begin{cases} (W_{N_A} - \dfrac{1}{h_{[\mathbf{d}]_i}}) > 0 & \text{if } i \in [1, N_A], \\ 0 & \text{if } i \in [N_A+1, N], \end{cases} \tag{8}$$

where W_{N_A} is the constant water level of the N_A active channels.

Altogether, the solution to (7) can be found by performing an exhaustive search from $N_A = 1$ to $N_A = N$ and evaluating the obtained power allocation in (8) into the objective function. However, this is a tedious work and requires a high computational complexity. So, in the following, we present a stopping criteria for the algorithm.

Assume that the algorithm is at the n-th iteration, i.e., $N_A = n$. For this value of N_A, the objective function is $\sum_{i=1}^{n} \log(h_{[\mathbf{d}]_i}W_n) = \log(W_n^n \prod_{i=1}^{n} h_{[\mathbf{d}]_i})$. Now, we want to see under which condition an additional channel is activated. Similarly as before, when $N_A = n+1$, the value of the objective function is $\log(W_{n+1}^{n+1} \prod_{i=1}^{n+1} h_{[\mathbf{d}]_i})$. Observe that $W_n > W_{n+1}$ since when $N_A = n+1$ there is less energy available due to the increment in the circuitry energy consumption and this energy is split into more time slots.

Therefore, the $[\mathbf{d}]_{n+1}$ time slot will only be activated if

$$h_{[\mathbf{d}]_{n+1}} W_{n+1}^{n+1} > W_n^n, \tag{9}$$

which follows from comparing the objective function in both cases. Note that if at the iteration $n+1$ the condition in (9) is not satisfied, then the optimal number of active slots is $N_A^\star = n$.

As in the previous section, the study carried out in this section allows us to upper bound the objective function in (3) as summarized in the following remark.

Remark 2. Let the initial battery β in problem (7) be equal to the total amount of energy harvested during the N time slots in (3), i.e., $\beta = \sum_{j=1}^{J} E_j$, then the optimal value of the objective function in (7) upper bounds the optimal value of the objective function in (3).

V. FADING CHANNEL WITH ENERGY HARVESTING

In this section, the problem (3) is solved. To do so, we apply some of the insights learned in the previous sections. First, from all the constraints in (3b), only the most restrictive ones are kept, i.e., the constraint in the last time slot of each pool. With this, the number of ECCs is reduced from N to J:

$$\max_{\{\rho_i\}_1^N,\{P_i\}_1^N} \quad \sum_{i=1}^{N} \rho_i \log(1+h_iP_i) \tag{10a}$$

subject to

$$\sum_{i=1}^{e_{\ell+1}-1} P_i+\rho_iP_c \leq \sum_{j=1}^{\ell} E_j/T_s, \qquad \ell = 1\ldots J, \tag{10b}$$

Observe that without loss of generality we can assume that the time slots within a certain pool have decreasing channel gains. For instance, for the j-th pool, $h_{e_j} \geq h_{e_j+1} \geq \cdots \geq h_{e_{j+1}-1}$. However, note that we cannot make any assumption regarding the inter-pool gains.[4]

As done in previous sections, to solve (10), we have three inherent problems: (i.) Determine the optimal number of active slots N_A. (ii.) Slot selection: Decide which are the N_A time slots to be used, i.e., determine $\mathbf{s}_{N_A}^\star$ among the $\binom{N}{N_A}$ possible combinations. (iii.) Power allocation: Decide the amount of power allocated in each of the active slots.

The approach taken to solve (10) is similar to the one in the previous section, we will perform a forward search over N_A until some stopping-criteria is met. Then, for every value of N_A, the optimal slot selection $\mathbf{s}_{N_A}^\star$ and its associated power allocation are found. Note that for a fixed slot selection, the optimal power allocation in the active slots is given by the DWF policy in (1).

Here, the main difficulty of the problem dwells in the slot selection. Observe that, for a given N_A, deciding the optimal slot selection is not as straightforward as before. As opposed to the cases considered in the previous sections, now there exists a clear trade-off between channel gain and energy availability. For instance, given that the optimal number of active slots is one, i.e., $N_A = \sum_i \rho_i = 1$, which is the optimal one? From the one hand, we could think of the time slot with the best channel gain, which will be the first time slot of some pool e_k for some $k \in [1, J]$. However, from the other hand, there may exist some time slot e_q with $k < q \leq J$ that, in spite of having a worse channel gain, achieves a higher mutual information due to the extra availability of energy harvested in $(e_k, e_q]$. So, among the $\binom{N}{N_A}$ possible slot selections of N_A slots which is the optimal one? To answer this question an

[4]Observe that having decreasing channel gains is not a limitation of our problem set up, we could also have used an indexing vector for each pool to sort the channel gains, as it is done in Section III. However, we prefer not doing so to keep the notation simple.

exhaustive search over the $\binom{N}{N_A}$ possible slot selections can be performed. Actually, the performance can be slightly increased by initially discarding some unfeasible slot selections such as a slot selection that contains some slot of a certain pool without containing all the slots of that same pool that have higher channel gains. However, the computational burden is still prohibitive, specially taking into account that $\mathbf{s}^\star_{N_A}$ must be found at every iteration of the forward search over N_A. To overcome this problem, we propose three suboptimal algorithms that greatly reduce the computational cost and that perform close to the optimal solution.

A. Incremental Slot Selection (ISS)

Before presenting the ISS suboptimal algorithm, let us introduce some definitions. Let $\mathbf{s}_x$ denote some slot selection among a total of $N_A = x$ slots. Let $\mathbf{w}$ be a $1 \times N$ vector containing the water level in each slot, which is obtained through DWF in the active slots as $[\mathbf{w}]_{i\in\mathbf{s}_x} = \frac{1}{h_i} + P_i$. The value of $[\mathbf{w}]_{i\notin\mathbf{s}_x}$ is not relevant since, as presented later, it is not utilized in the remaining derivations. Note that due to the definition of the DWF, the water level remains constant throughout all the active slots belonging to a certain pool $[\mathbf{w}]_{i\in\mathbf{s}_x} = W_{\tau_j}$, $i \in \tau_j$, for some $W_{\tau_j} > 1$ that is the j-th pool's water level.

Moreover, let us define the water factor when x channels are active as $F_{\mathbf{s}_x} = \prod_{i\in\mathbf{s}_x}[\mathbf{w}]_i h_i$. Observe that the sum rate is directly the logarithm of the water factor, i.e., $\log F_{\mathbf{s}_x}$. Then, $\mathbf{s}^\star_x$ is the slot selection that achieves a higher water factor among the $\binom{N}{x}$ possibilities.

The ISS suboptimal algorithm assumes that $\mathbf{s}^\star_{x+1}$ contains the slot selection in $\mathbf{s}^\star_x$ plus some additional slot $s_k \notin \mathbf{s}^\star_x$, i.e., $\mathbf{s}^\star_{x+1} = \{\mathbf{s}^\star_x, s_k\}$. According to this assumption, the algorithm is able to reduce the search over the $\binom{N}{x}$ possible slot selections required by the optimal algorithm to at most J (as the slot s_k is necessarily the first non-used slot of some pool).

To compute the solution, we need a list for each pool l_j^{NA} that contains the non-active slots ordered with decreasing channel gain. Initially, this list contains all the pool's slots, i.e., $l_j^{NA} = \{e_j, e_j+1, \ldots e_{j+1}-1\}, \forall j$. We also need another list that keeps track of the active slots, which initially is empty, i.e., $l_j^A = \{\emptyset\}, \forall j$. In the following, we present the developed strategy to solve the problem:

1) Initially, set $N_A = 1$ and $F_{\mathbf{s}_0} = 0$.
2) Incremental slot selection:
   For all the pools τ_j with available slots:
   a) Perform DWF with the previous allocated slots $\{l_j^A\}_{j=1}^J$ and with an additional slot s_j that is the first element in l_j^{NA}, i.e., $s_j = l_j^{NA}(1)$ (taking into account the circuitry consumption of all the involved slots).
   b) Compute the resulting water factor.

   Let $s_{j^\star}$ be the additional slot that achieves the highest water-factor in 2b. The maximum water-factor is stored in the variable $F_{\mathbf{s}_{N_A}}$.
3) Check the stopping criteria:
   - If $F_{\mathbf{s}_{N_A}} > F_{\mathbf{s}_{N_A-1}}$, the slot $s_{j^\star}$ must be used as it achieves a higher mutual information. Add the slot to $l_{j^\star}^A$ and remove it from $l_{j^\star}^{NA}$. Increase N_A by one and go back to 2.
   - If $F_{\mathbf{s}_{N_A}} \leq F_{\mathbf{s}_{N_A-1}}$, the use of $s_{j^\star}$ is not worth it as it does not achieve a higher mutual information due to the circuitry power consumption. Then, $N_A^\star = N_A - 1$, the optimal slots are the ones in the active-slot lists $\mathbf{s}^\star_{N_A^\star} = \{l_j^A\}_{j=1}^J$, and the power allocation is given by DWF.

As shown in Section VI, the ISS algorithm determines a solution that achieves a throughput very close to the one achieved with the optimal solution. Moreover, the required computational burden is much lower as for every value of N_A in the forward search, it is necessary to compute J times the DWF in [6] instead of the $\binom{N}{N_A}$ times required by the optimal algorithm. Unfortunately, the ISS may still be unfeasible for large problem dimensions. To overcome this, Subsections V-B and V-C introduce two alternative suboptimal algorithms that behave close to the ISS and that further reduce the computational burden.

B. Maximum Gain Slot Selection (MGSS)

This suboptimal algorithm reduces the complexity of the slot selection step. The algorithm proceeds as the ISS presented in Section V-A but the slot selection performed in the step 2 is radically simplified by just picking the slot from the non-active lists, $\{l_j^{NA}\}_{j=1}^J$, that has the highest channel gain.

C. Weighted Slot Selection (WSS)

This suboptimal algorithm aims at improving the MGSS, presented in the previous section, by also taking into account the availability of energy of each time slot. Let s_j denote the first time slot in the non-active list of the j-th pool, i.e., $s_j = l_j^{NA}(1)$, $j = 1, \ldots, J$. Then, for a certain N_A, the slot selection is given by the slot selection obtained in the previous iteration plus some additional slot $s_{j^\star}$, i.e., $\mathbf{s}_{N_A} = \mathbf{s}_{N_A-1} \cup \{s_{j^\star}\}$. The pool from which the additional slot is taken can be obtained as a weighted sum of the gain and the energy availability, i.e.,

$$j^\star = \arg\max_{j: s_j \in \mathcal{S}} h_{s_j} + w\frac{E_H(j) - N_j P_c}{E_H(J) - N_A P_c}, \qquad (11)$$

where N_j is the number of active slots up to the j-th pool plus the additional slot and can be computed as $N_j = 1 + \sum_{i=1}^{e_{j+1}-1} \rho_i$, where the value for ρ_i can be directly assigned from $\mathbf{s}_{N_A-1}$. The set $\mathcal{S}$ contains the slots that can be activated without breaking the ECC in the corresponding pool, i.e., $\mathcal{S} = \{s_j | E_H(j) - N_j P_c \geq 0\}$. Note that $\frac{E_H(j)-N_jP_c}{E_H(J)-N_AP_c}$ is a normalized measure of the available energy in the j-th pool that is 1 for the J-th pool and a value in $[0, 1)$ for all the other pools such that $s_j \in \mathcal{S}$. Then, as $h_{s_j} \in [0, 1]$ the weight w is used to select between channel gain and energy availability.[5]

As before, the implementation of the algorithm is the same than the one in Section V-A but the slot selection performed in the step 2 is exchanged by the WSS.

[5]Note that if $w = 0$ the WSS is equivalent to the MGSS.

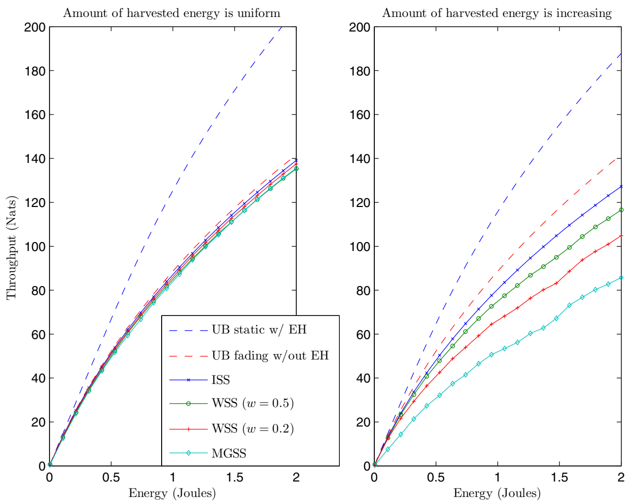

Figure 2. Achieved throughput for the different algorithms. In the left plot, the amounts of energy in the packets are uniformly distributed. In the right plot, energy arrivals are sorted in increasing order.

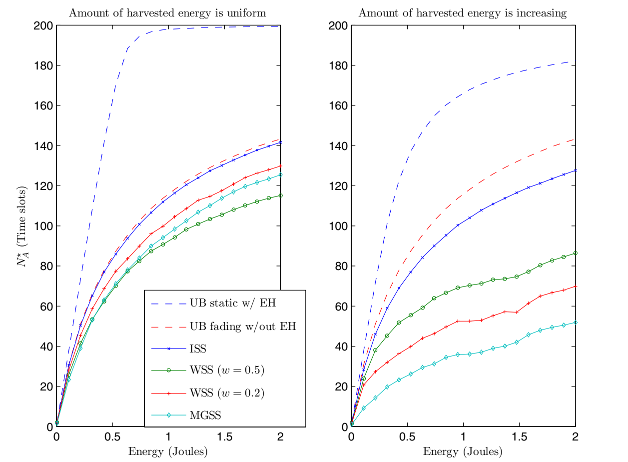

Figure 3. Optimal number of active channels for the different algorithms. In the left plot, the amounts of energy in the packets are uniformly distributed. In the right plot, energy arrivals are sorted in increasing order.

VI. Results

We have considered a fading channel with randomly generated channel gains, where the total transmission time is NT_s seconds with $N = 200$ and $T_s = 5\ ms$, in which the node is able to harvest $J = 40$ energy packets. The circuitry power consumption is $P_c = 100\ mW$. Energy arrivals are uniformly distributed along transmission slots and with random amounts of energy, which are normalized by the total energy harvested that varies along the x-axis of Figures 2 and 3. In the right subplots of Figures 2 and 3, energy arrivals have been ordered in increasingly.[6] Figure 2 shows the total achieved throughput. The different solid curves are the results obtained through the different suboptimal algorithms, namely, the ISS, the MGSS, and the WSS for $w = 0.5$ and $w = 0.2$. The dashed lines represent the upper bounds obtained from Remarks 1 and 2. We have not been able to show the throughput obtained with the optimal algorithm due to the required complexity, however, we know that it is located between the lowest upper bound and the ISS suboptimal solution. As the difference between the lowest upper bound and the ISS is small, we can provably state that the ISS performs close to the optimal solution to (3). The simulation results confirm that due to ECCs for a given fixed amount of harvested energy, the later the energy is available, the less throughput is achieved. Note that when the harvested energy is uniformly distributed (left plot) all the suboptimal strategies perform close to the optimal.[7] However, when the energy harvesting process becomes more relevant (right plot) the algorithms diverge from the optimal and the best performance is achieved by the ISS.

Finally, Figure 3 shows the optimal number of active slots obtained in the previous setup. Note that the number of active time slots increases with the harvested energy and that the ISS is the algorithm that performs closest to the upper bound.

[6]This could model the energy harvested by a solar panel during sunrise.

[7]The trade-off between channel gain and energy availability is dominated by channel gain.

VII. Conclusions

In next generation energy efficient network topologies, long range transmissions will be avoided by means of cooperation among the network nodes. In the short range communication framework, the circuitry power consumption is comparable to the transmission power and, hence, it must be taken into account when designing optimal transmission strategies. Moreover, energy harvesting enables to increase the lifetime span of autonomous wireless devices.

In this context, in this paper we have derived the power allocation and slot selection that maximize the total throughput of a wireless energy harvesting node operating in a slow fading channel. The high computational complexity of the optimal algorithm makes it non-implementable when the dimensions of the problem are large. To solve this, we have suggested three suboptimal algorithms that reduce a great deal the computation of the slot selection and that achieve throughputs close to the one obtained with the optimal algorithm.

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