The Energy Harvesting Multiple Access Channel with Energy Storage Losses

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***Abstract*—This work considers a Gaussian multiple access channel with two energy harvesting transmitters with lossy energy storage. The power allocation policy maximizing the average weighted sum rate given the energy harvesting profiles is found. In particular, it is shown that the optimal policy has a double-threshold structure on each of the transmit powers, while the two transmit powers interact through the multivariate achievable rate function which determines the thresholds. For the special case of sum rate maximization in a Gaussian MAC channel, it is shown that the thresholds apply to the sum power, and the optimal policy consists of three thresholds, rather than four, which enables the user with a more efficient battery to be given priority in energy storage.**

I. Introduction

Energy harvesting wireless nodes provide prolonged network lifetime while building a foundation for green communications. Such nodes are particularly attractive for wireless network deployment where frequent replacement of batteries of nodes is not practical, such as wireless sensor networks, body networks, or dynamic communication scenarios for military applications. A fundamental limitation of energy harvesting wireless nodes is the scarcity and intermittent availability of the energy source. Consequently, care must be given to storage and effective utilization of harvested energy in order to achieve desired network performance. As energy storage in practice is not perfectly efficient, the trade-off between storage and consumption of harvested energy arises as an important factor to be considered in network design. In this work, we consider this trade-off in a Gaussian energy harvesting multiple access channel and find optimal power allocation policies in the presence of energy storage losses.

Wireless nodes with energy harvesting as their sole energy source has sparked interest in recent years [1]–[9]. Since a key challenge in these works is energy management, the focus has been on optimal power allocation. In [1], transmission time minimization has been studied for a single energy harvesting transmitter with infinite energy storage. The model has been extended to finite capacity energy storage in [2], which also showed the duality between transmission time minimization and average rate maximization problems for energy harvesting transmitters. This work is followed by the energy harvesting broadcast channel [3], multiple access channel [4], interference channel [5], and a two-hop network [6]. For Gaussian fading channels, a directional water-filling algorithm is introduced in reference [7].

In energy harvesting wireless networks, to enable operation, an energy storage device such as a battery or a supercapacitor is necessary. However, such devices may be inefficient, have a rate-dependent capacity, and may suffer from storage capacity fading, leakage, and recovery effects. In [10], [11], some electrical models for energy storage devices are proposed. Some of these imperfections, namely capacity fading and leakage, are studied in [8] for energy harvesting networks by modifying the single-user policy in [1], [2]. In this work, we adopt the storage loss model in reference [12], i.e., the loss is a fraction of the stored energy, which is used to find optimal duty-cycling for energy-neutrality in nodes with infinite batteries.

We focus on a multiple access channel with two energy harvesting transmitters, each equipped with finite and lossy energy storage devices. The single energy harvesting transmitter problem under such constraints is studied in [13], yielding a double-threshold policy on the transmission power. The multiple access extension of this problem, as examined in this paper, additionally considers the interplay between the two transmitters, and how the thresholds are related. It is shown that the weighted sum rate maximizing policy can be found by an iterative alternating maximization algorithm, where each iteration is a modified version of the single user problem, yielding a similar double-threshold result. For the special case of sum rate maximization in a Gaussian MAC, it is shown that the optimal policy consists of three thresholds on the sum power, with storage priority given to the transmitter with a more efficient energy storage.

II. System Model and Problem Definition

We consider two energy harvesting transmitters with lossy energy storage communicating to a common receiver. This defines the energy harvesting multiple access channel as shown in Figure 1. Each transmitter is equipped with a battery of finite capacity E_i^{max} in which it can store the harvested energy and from which it can discharge the stored energy in the future. Hence, the instantaneous transmission power of an energy harvesting node is determined by the harvested power, stored power and the retrieved power at an instant, while the stored and retrieved powers are constrained by causality and the physical properties of the storage device.

What distinguishes this work from previous works on scheduling with energy harvesting nodes such as [1], [2], [6],

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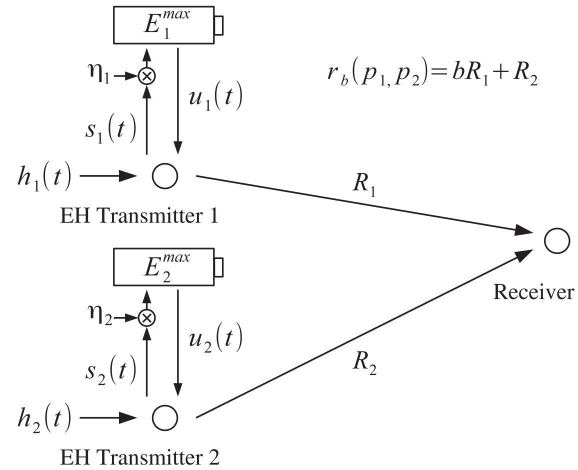

Fig. 1. The energy harvesting multiple access channel.

[7] is that the energy storage process is lossy, in the sense that a constant fraction η_i of the stored power in transmitter i is lost due to practical inefficiencies. Although this loss can be both at the storage and the retrieval stages, it can equivalently be modeled as a loss at the storage stage only by scaling the storage capacity accordingly. This loss model is has been used as an appropriate model before [12], [13].

As depicted in Figure 1, the harvested power at time t for transmitter i is denoted with $h_i(t)$. Out of this arriving power, $s_i(t)$ is scheduled for storage, and $\eta_i s_i(t)$ is stored in the device while the remaining energy $(1-\eta_i)s_i(t)$ is lost to inefficiency. The rate of energy retrieval from the storage device is denoted with $u_i(t)$. The transmission power $p_i(t)$ for transmitter i, $i = 1, 2$, is therefore expressed as

$$p_i(t) = h_i(t) - s_i(\tau) + u_i(\tau). \tag{1}$$

The nodes are free to allocate the available power to the transmitter or storage device, and thus the variables of the problem are $s_i(t)$ and $u_i(t)$ which determine the transmit power $p_i(t)$. The harvested power $h_i(t)$ is not controlled, but is assumed to be known non-causally for the offline problem in order to find the optimal policy. The variables $s_i(t)$ and $u_i(t)$ are constrained by the harvested power, energy causality and battery capacity. Naturally, no more than the harvested power $h_i(t)$ can be scheduled to be stored at any time t, and hence $s_i(t) \leq h_i(t)$ for all t. Assuming that the storage device is initially empty, the energy stored at time t is given by

$$E_i^{bat}(t) = \int_0^t \eta_i s_i(\tau) - u_i(\tau)\ d\tau \tag{2}$$

To conform to reality, the value of $E_i^{bat}(t)$ shall never fall below 0 and shall never exceed the capacity E_i^{max}. The former constraint implies that no more than the stored energy can be retrieved by the transmitter. This is named energy causality, and is expressed as

$$\int_0^t \eta_i s_i(\tau) - u_i(\tau)\ d\tau \geq 0, \qquad 0 \leq t \leq T \tag{3}$$

while the latter constraint, battery capacity, is given by

$$\int_0^t \eta_i s_i(\tau) - u_i(\tau)\ d\tau \leq E_i^{max}, \qquad 0 \leq t \leq T. \tag{4}$$

Given the instantaneous transmission powers of the two users as p_1 and p_2, the rate pairs (R_1, R_2) that can be achieved are given by an achievable region $\Re(p_1, p_2)$. It is trivial that this region is concave, since time-sharing allows any convex combination of achievable rates to also be achieved. Note that channel coefficients are not considered in this expression, but they can easily be handled by properly scaling the harvested powers $h_i(t)$ of the transmitters to get an equivalent model and achievable region.

We define the utility of the system as the average weighted short-term sum rate $bR_1 + R_2$, calculated by averaging the instantaneous achievable weighted sum rate through the transmission duration, T. Since the instantaneous rates are added in this problem formulation, it is optimal to choose the weighted sum rate maximizing rate pair out of $\Re(p_1, p_2)$ at each instant where a power pair (p_1, p_2) is given. For a weight b, we denote the maximum achieved weighted sum rate as $r_b(p_1, p_2)$. Together with the constraints on stored and retrieved powers, the offline average weighted sum rate maximization problem with transmission deadline T is given by

$$\max_{s_i(t), u_i(t)} \ \frac{1}{T} \int_0^T r_b(p_1(t), p_2(t))\ dt \tag{5a}$$

$$\text{s.t. } 0 \leq \int_0^t \eta_i s_i(\tau) - u_i(\tau)\ d\tau \leq E_i^{max}, \tag{5b}$$

$$h_i(t) \geq s_i(t) \geq 0,\ u_i(t) \geq 0, \quad 0 \leq t \leq T \tag{5c}$$

where $p_i(t)$ is given in (1) and $i \in \{1, 2\}$. The solution to the single-user version of this problem is provided in [13] as a double-threshold power policy. In this paper, we analyze and solve the two transmitter extension of this problem given in (5). While we present the two-transmitter scenario in detail for clarity of exposition, we note that the problem and the approach can be readily extended to more than two transmitters.

III. Optimal Transmission Policy

For the multiple access channel, the weighted sum rate maximization problem is defined in (5). To solve for the optimal power policy, we first show the convexity of this problem. It is trivial that the feasible set for $(s_i(t), u_i(t))$ is convex, since the constraints in (5b) and (5c) are linear. What remains is the joint concavity of the function in the objective $r_b(p_1, p_2)$ in the transmission powers p_1 and p_2.

Lemma 1: The achievable instantaneous weighted sum rate $r_b(p_1, p_2)$ for a given weight b is non-decreasing, continuous and jointly concave in p_1 and p_2.

Proof: The non-decreasing property follows from the transmitters discarding excess transmission power from p_1, p_2 or both to achieve any weighted sum rate provided by $p_1' \leq p_1$ and $p_2' \leq p_2$. Continuity and joint concavity can be proved with time sharing between two or more rate vectors. In a small neighborhood of (p_1, p_2), a weighted sum rate r_b arbitrarily close to $r_b(p_1, p_2)$ can be achieved by discarding power greater than p_1 or p_2 and transmitting with (p_1, p_2)

for a slightly shorter time period so that the average transmit power is as desired. Similarly for concavity, if two sum rates r_b' and r_b'' can be achieved with (p_1', p_2') and (p_1'', p_2'') respectively, then time-sharing between these two power vectors can achieve any convex combination of the two weighted sum rates, thus proving concavity of $r_b(p_1, p_2)$ in p_1 and p_2. ■

Remark 1: The critical assumption at this step is the availability of time-sharing for achieving an instantaneous weighted sum rate. Although this may not always be possible when considered on a time scale comparable to the codeword length, it is not impractical on longer time scales, i.e., when the transmission time is much greater than a codeword, as is frequently the case in practice.

As a consequence of Lemma 1, the maximization problem in (5) is convex. We then seek some properties of the optimal power allocation using the Karush-Kuhn-Tucker (KKT) conditions for this problem. The Lagrangian function is given in (6), where $\lambda_i(t)$, $\beta_i(t)$, $\mu_i(t)$, $\sigma_i(t)$ and $\nu_i(t)$ are the Lagrangian multipliers for the constraints in (5b) and (5c).

The KKT stationarity conditions are found by differentiating the Lagrangian function $\mathcal{L}$ over $s_i(t)$ and $u_i(t)$, $i = 1, 2$,

$$\frac{\partial r(p_1(t), p_2(t))}{\partial p_1} = \eta_1 \int_t^T \lambda_1(\tau)\ d\tau + \mu_1(t) - \sigma_1(t) \tag{7a}$$

$$\frac{\partial r(p_1(t), p_2(t))}{\partial p_2} = \eta_2 \int_t^T \lambda_2(\tau)\ d\tau + \mu_2(t) - \sigma_2(t) \tag{7b}$$

$$\frac{\partial r(p_1(t), p_2(t))}{\partial p_1} = \int_t^T \lambda_1(\tau)\ d\tau - \nu_1(t) \tag{7c}$$

$$\frac{\partial r(p_1(t), p_2(t))}{\partial p_2} = \int_t^T \lambda_2(\tau)\ d\tau - \nu_2(t) \tag{7d}$$

Observing (7a) and (7c) for user 1 and (7b) and (7d) for user 2 separately, it can be concluded that the optimal power policy for each user separately follows the same properties with the single user double-threshold policy in [13]. Therefore, the double-threshold policy for transmitter j with energy harvest $h_j(t)$ consists of the following three modes:

1) **Storage:** If $h_j(t) > p_{sj}(t)$, the upper threshold, then transmit with $p_{sj}(t)$ and store the excess power.
2) **Retrieval:** If $h_j(t) < p_{uj}(t)$, the lower threshold, then transmit with $p_{uj}(t)$ by retrieving the missing power.
3) **Passive:** If $p_{uj}(t) \leq h_j(t) \leq p_{sj}(t)$, then transmit with $h_j(t)$ without storing or retrieving energy.

The two thresholds are related with $\frac{\partial/\partial p_j\ r(p_s(t))}{\partial/\partial p_j\ r(p_u(t))} = \eta_j$, $j = 1, 2$. For the single transmitter, the thresholds are found to be piecewise constant and changing only at the extreme values of the stored energy. This allows the exact thresholds to be calculated by searching feasible threshold pairs for one satisfying these optimality conditions. The specifics on how to find the threshold values for the single user problem can be found in [13]. In contrast to the single user problem, the thresholds of the multiple access case are not necessarily constant, since they depend on all transmission powers through the partial derivative $\frac{\partial r_b(p_1(t), p_2(t))}{\partial p_j}$. This can be seen for transmitter 1 by comparing (7a) and (7c) at storage and retrieval modes respectively with Lagrangian multipliers chosen based on the KKT complementary slackness conditions. Hence the optimal policy is interactive in the sense that the thresholds of the power of a user depends on the transmission power of the *interfering user*, each user having its own pair of thresholds.

Given this preparation, we are now ready to utilize the convexity of the problem and propose an iterative solution. In particular, we solve this problem through an alternating maximization algorithm [14], where at each iteration a user assumes the transmission power of the other user to be fixed and finds the optimal policy. For example, on the k^{th} iteration, transmitter 1 determines its transmission policy ($s_1^{[k]}(t)$,$u_1^{[k]}(t)$) by solving the single-user problem [13]

$$\max_{s_1(t), u_1(t)} \frac{1}{T} \int_0^T r(p_1(t), p_2^{[k-1]}(t))\ dt \tag{8a}$$

$$\text{s.t. } 0 \leq \int_0^t \eta_1 s_1(\tau) - u_1(\tau)\ d\tau \leq E_1^{max}, \tag{8b}$$

$$h_1(t) \geq s_1(t) \geq 0,\ u_1(t) \geq 0, \quad 0 \leq t \leq T \tag{8c}$$

where $p_2^{[k-1]}(t)$ is fixed as the output of the previous iteration. The solution to this single transmitter problem is a two-threshold policy. However, since the rate function is multivariate, the thresholds are related as

$$\frac{\partial/\partial p_1\ r(p_s, p_2^{[k-1]})}{\partial/\partial p_1\ r(p_u, p_2^{[k-1]})} = \eta_1 \tag{9}$$

On the $k + 1^{st}$ iteration, the same process is repeated for the second transmitter and the iterations continue until convergence. This iteration, namely block coordinate descent, can be shown to converge to the global minimum objective value [14], see also [5].

IV. Special Case: Sum Rate Maximization

A special case of (5) is the sum rate case, i.e., $b = 1$, with Gaussian noise and a virtually infinite storage, for which the sum-capacity is given by

$$r_1(p_1, p_2) = R_1 + R_2 = \frac{1}{2} \log\left(1 + \frac{p_1 + p_2}{N}\right) \text{ bits/ch. use.} \tag{10}$$

This case yields an explicit solution due to this rate expression being a function of $p_1 + p_2$. In fact, when $r_1(p_1, p_2)$ is rearranged to be expressed as $r_1(p_1 + p_2)$, we can observe a strict concavity in $p_1 + p_2$ along with continuity and monotonicity. In this case, the KKT conditions in (7) all share the same partial derivative term, since $\frac{\partial r_1(p_1, p_2)}{\partial p_i} = \frac{\partial r_1(p)}{\partial p}$ where $p = p_1 + p_2$ is the sum power.

A direct consequence of the achieved utility being only a function of $p_1 + p_2$ is the indifference of the system to how much of the sum power is provided by either user. Therefore, once some energy is stored in either of the batteries, the performance of the system is independent of which battery this energy is stored in, since it can be restored with identical contribution to the sum power. This forms the grounds for the equivalent model we propose to simplify the multiple access problem as follows:

We define the *multiple harvesters with shared storage* model as a single transmitter node powered by two harvesting processes $h_1(t)$ and $h_2(t)$, which can be stored in a common battery with efficiency η_1 and η_2 respectively, or used directly

$$\mathcal{L} = \int_0^T r_b(p_1(t), p_2(t))\ dt + \sum_{i=1}^{2} \left(\int_0^T \lambda_i(t) \int_0^t \eta_i s_i(\tau) - u_i(\tau)\ d\tau\ dt + \int_0^T \beta_i(t) \left(E_i^{max} - \int_0^t \eta_i s_i(\tau) - u_i(\tau)\ d\tau \right) dt + \right.$$
$$\left. \int_0^T \mu_i(t)(h_i(t) - s_i(t))\ dt + \int_0^T \sigma_i(t) s_i(t)\ dt + \int_0^T \nu_i(t) u_i(t)\ dt \right) \quad (6)$$

in transmission. The stored power for the ith harvesting process is denoted with $s_i(t)$, and the power drawn from the battery is denoted with $u(t)$. This model is depicted in Figure 2. The problem of maximizing the average rate for this transmitter given a rate function $r(p)$ is expressed as

$$\max_{s_1(t), s_2(t), u(t)} \frac{1}{T} \int_0^T r(h(t) - s_1(t) - s_2(t) + u(t))\ dt \quad (11a)$$
$$\text{s.t. } 0 \leq \int_0^t \eta_1 s_1(\tau) + \eta_2 s_2(\tau) - u(\tau)\ d\tau, \quad (11b)$$
$$h_i(t) \geq s_i(t) \geq 0, \quad u(t) \geq 0, \quad 0 \leq t \leq T. \quad (11c)$$

Note that since sum capacity is only a function of sum-power in a Gaussian multiple access channel, this maximization problem is a relaxed version of the original problem in (5) which additionally allows exchanging the energy stored in the two batteries of the MAC users. Therefore, the maximum average sum rate achievable by the shared storage system is not less than that of the multiple access problem. We shall first find the optimal policy for this model that maximizes the average sum rate, and then claim that the same policy can be employed in the multiple access model with physically separate energy storage devices.

In the case with equal efficiency, i.e., $\eta_1 = \eta_2$, the model in Figure 2 would be equivalent to the single user model in [13] since the harvests $h_1(t)$ and $h_2(t)$ can effectively be considered cumulatively. In this case, the optimal policy can be found by a double threshold on the sum power, and either of the sources being stored when total harvested power is above a threshold. For the remainder of this section, we shall focus on the case $\eta_1 \neq \eta_2$ and assume, without loss of generality, that $\eta_1 < \eta_2$.

For the shared storage problem in (11), the KKT stationarity equations relating to s_1 and s_2 are identical to (7a) and (7b), except with a common Lagrange multiplier $\lambda(t)$. However, since a single battery is considered, (7c) and (7d) are replaced with (14), yielding the KKT conditions

$$r'(p(t)) = \eta_1 \int_t^T \lambda(\tau)\ d\tau + \mu_1(t) - \sigma_1(t) \quad (12)$$
$$r'(p(t)) = \eta_2 \int_t^T \lambda(\tau)\ d\tau + \mu_2(t) - \sigma_2(t) \quad (13)$$
$$r'(p(t)) = \int_t^T \lambda(\tau)\ d\tau - \nu(t) \quad (14)$$

where $p(t) = h_1(t) + h_2(t) - s_1(t) - s_2(t) + u(t)$ is the transmission power of the user. The corresponding complementary slackness conditions for each Lagrangian multiplier are

$$\lambda(t) \left(\int_0^t \eta s_1(\tau) + s_2(\tau) - u(\tau)\ d\tau \right) = 0 \quad (15a)$$
$$\mu_1(t)\left(h_1(t) - s_1(t)\right) = 0,\ \mu_2(t)\left(h_2(t) - s_2(t)\right) = 0 \quad (15b)$$
$$\sigma_1(t) s_1(t) = 0, \quad \sigma_2(t) s_2(t) = 0, \quad \nu(t) u(t) = 0. \quad (15c)$$

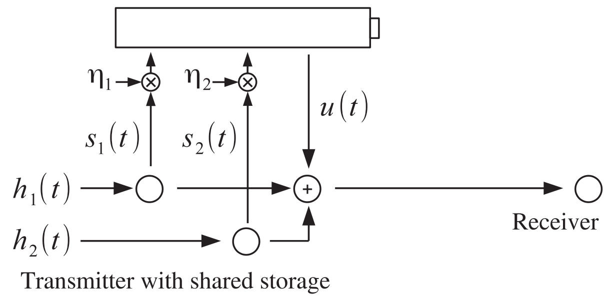

Fig. 2. Equivalent system model for two transmitters with shared storage

We briefly look at the possible cases for this system while skipping some trivial cases due to lack of space.

Case 1: Simultaneous charging and discharging

In the case with $u(t) > 0$ and $s_i(t) > 0$ for some $i \in \{1, 2\}$, we have $\nu(t) = \sigma_i(t) = 0$ due to (15). Combining (14) and (12,13), we get

$$r'(p(t)) = \int_t^T \lambda(\tau)\ d\tau = \eta_i \int_t^T \lambda(\tau)\ d\tau - \mu_i(t) \quad (16)$$

which cannot hold for $\mu_i(t) \geq 0$ and $0 \leq \eta_i < 1$. For the special case with $\eta_i = 1$, we can find an equivalent policy that yields the same transmission power without simultaneous charging and discharging. Thus, this case will be avoided in the optimal policy.

Case 2: Discharge only

For the case of discharging only, $u(t) > 0$, the complementary slackness conditions yield $\nu(t) = 0$. Substituting in (14), this gives

$$r'(p(t)) = \int_t^T \lambda(\tau)\ d\tau \quad (17)$$

implying that the transmission power at which the battery is discharging is constant while the battery is non-empty, and this constant level is non-decreasing due to the fact that $\lambda \geq 0$. As in the single user case in [13], we shall denote this discharge threshold power as p_u.

Case 3: Charging using both harvests

When both $h_1(t)$ and $h_2(t)$ are being stored, we have $\sigma_1(t) = \sigma_2(t) = 0$. Substituting in (12) and (13), we get

$$r'(p(t)) = \eta_1 \int_t^T \lambda(\tau)\ d\tau - \mu_1(t) = \eta_2 \int_t^T \lambda(\tau)\ d\tau - \mu_2(t). \quad (18)$$

Recall that $\eta_1 < \eta_2$ by assumption. This would mean that if $h_2(t) > s_2(t)$, i.e., if the more efficiently stored harvest is not being stored as a whole, we get $\mu_2(t) = 0$ and the above equation cannot hold with $\mu_1(t) \geq 0$. Therefore, we can conclude that both harvests cannot be stored unless $s_2(t) = h_2(t)$, i.e., that the harvest with higher efficiency must always have storage priority over the other one.

Case 4: Charging with harvest i only

When $s_i(t) > 0$ only, complementary slackness conditions yield $\sigma_i(t) = 0$. Substituting in (12) or (13) gives

$$r'(p(t)) = \eta_i \int_t^T \lambda(\tau)\ d\tau - \mu_i(t) = 0. \tag{19}$$

Therefore, unless all harvested power is being stored, $\mu_i(t)$ is zero and the transmission power at which charging for harvest i occurs is constant while $E_{bat} > 0$. Comparing to (17), we see that this power, denoted as p_{si}, satisfies

$$\frac{r'(p_{si})}{r'(p_u)} = \eta_i. \tag{20}$$

Finally, note that for $i = 1$, if $h_2(t) > 0$, then $\mu_2(t) = 0$, yielding

$$r'(p(t)) = \eta_1 \int_t^T \lambda(\tau)\ d\tau - \mu_1(t) = \eta_2 \int_t^T \lambda(\tau)\ d\tau + \sigma_2(t) \tag{21}$$

which cannot hold for non-negative $\mu_1(t)$ and $\sigma_2(t)$. Thus, complementing the priority statement in the previous case, charging with harvest 1 only occurs when $h_2(t) = 0$.

The cases analyzed above outline sufficient requirements to find an optimal policy for the shared storage model. Given the three thresholds p_u, p_{s1} and p_{s2}, the transmitter operates in one of the five modes below:

1) Both harvests being stored, $s_2(t) = h_2(t)$, $p(t) = p_{s1}$,
2) $h_1(t)$ being stored only, $p(t) = p_{s1}$
3) $h_2(t)$ being stored only, $p(t) = p_{s2}$,
4) Battery is discharging, i.e., $u(t) > 0$, with $p(t) = p_u$,
5) No charging or discharging occurs.

The three thresholds that govern these modes are necessarily ordered as $0 \leq p_u \leq p_{s2} \leq p_{s1}$ with the second harvest with better efficiency, i.e., $\eta_2 > \eta_1$, having storage priority. The transmission power at which discharging occurs, $p_u(t)$ is constant while $E_{bat} > 0$ and non-decreasing. Furthermore, given $p_u(t)$, the charging thresholds for both harvests can be found through (20). The problem reduces to finding a sequence of levels for $p_u(t)$ that deplete the stored energy whenever the levels are changing. The solution can be easily found by searching for the smallest p_u to deplete the battery at some time $0 < t_1 \leq T$, similar to the line search proposed in [13] for the single user problem.

Remark 2: The optimal policy derived above for the shared storage model can be feasibly implemented in the multiple access setting. An important property of the policy is that the performance of the system does not depend on which of the two batteries of the two transmitters is supplying the required power. Thus, when the nodes store energy based on thresholds p_{s1} and p_{s2} with the corresponding constraints in Cases 3 and 4 holding, the discharge rate $u(t)$ can be satisfied by either of the batteries. The optimal policy for the multiple access scenario is therefore a triple-threshold policy acting on the sum-power, with thresholds determined by (17) and (20) and the threshold levels are found by a line search algorithm.

V. Conclusion

In this paper, we have identified the optimal transmit power policy for energy harvesting transmitters with storage losses sharing a medium in a multiple access setting. We have shown that the problem can be solved by an alternating maximization algorithm where each iteration step is effectively a single-user problem. For this problem, the optimal policy is a double-threshold policy on each transmitter with thresholds related through the energy loss rate. For the special case of sum rate maximization in a Gaussian multiple access channel, we have shown that the thresholds act on the sum-power, and the optimal policy has a three threshold structure with storage priority given to the user with a more efficient storage. The results of this work can be extended to more than two receivers when a simple multiple access scenario is considered. Future work may include analysis of such networks with multiple destinations and energy harvesting relays, exploiting different paradigms such as routing.

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