Using Real-Time Backward Traffic Difference Estimation for Energy Conservation in Wireless Devices

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***Abstract*—This work proposes a scheme for sharing resources using the opportunistic networking paradigm whereas, it enables Energy Conservation (EC) by allocating Real-Time Traffic-based dissimilar Sleep/Wake schedules to wireless devices. The scheme considers the resource sharing process which, according to the duration of the traffic through the associated channel, it impacts the Sleep-time duration of the node. The paper examines the traffic's backward difference in order to define the next Sleep-time duration for each node. The proposed scheme is being evaluated through Real-Time implementation by using dynamically moving MICA2dot wireless nodes which, are exchanging resources in a Mobile Peer-to-Peer manner. Various performance metrics were considered for the thorough evaluation of the proposed scheme. Results have shown the scheme's efficiency for enabling EC and provide a schematic way for minimizing the Energy Consumption in Real-Time, in contrast to the delay variations between packets; whereas the proposed scheme aims at maximizing the efficiency of resource exchange between mobile peers.**

Keywords-Energy Conservation Scheme; Lifespan Extensibility Metrics; Resource Exchange for Energy Conservation Scheme; Opportunistic Communication Performance; Traffic-oriented Energy Conservation.

I. INTRODUCTION

As wireless nodes communicate over error-prone wireless channels with limited battery power, reliable and energy-efficient data delivery is crucial. These characteristics of wireless nodes make the design of resource exchange schemes challenging [1]. Due to the fact that wireless devices in order to conserve energy switch their states between Sleep mode, Wake mode and Idle mode, the responsiveness of these devices is reduced significantly. These devices, while being in the process of sharing resources, face temporary and unannounced loss of network connectivity as they move, whereas, they are usually engaged in rather short connection sessions since they need to discover other hosts in an ad-hoc manner. In most cases the requested resources claimed by these devices, may not be available. Therefore, a mechanism that faces the intermittent connectivity problem and enables the devices to react to frequent changes in the environment, while it enables energy conservation in regards to the requested traversed traffic, is of great need. This mechanism will positively affect the end-to-end reliability, facing the unavailability and the scarceness of wireless resources.

This work proposes a backward estimation model for extracting the time-oriented differential traffic in contrast to the resource capacity characteristics in order to offer Energy Conservation and availability of the requested resources. The proposed scheme uses the cached mechanism for guaranteeing the requested resources and the monitored traffic that traverses the nodes, both as input (basis for estimating the next sleep time duration of each node). This mechanism follows the introduced Backward Traffic Difference (BTD) scheme. The designed model guarantees the end-to-end availability of requested resources while it reduces significantly the Energy Consumption and maintains the requested scheduled transfers, in a mobility-enabled cluster-based communication. The innovative aspect of this work is that each node uses different assignment(s) of sleep-wake schedule estimation, based on the traffic difference through time. The Sleep-time duration is assigned according to the scheme in a dissimilar form to enhance node prolonged hibernation (where needed), whereas it avoids mutation which, will result in network partitioning and resource sharing losses. Real-Time experiments using various newly introduced metrics' estimations, were carried-out for the energy conservation and the evaluation of the proposed model. The scheme takes into account a number of metrics hosted by the proposed scheme, as well as estimation of the effects of incrementing the sleep time duration to conserve energy. Likewise, the Real-Time experiments show that different types of traffic can be supported where the adaptability and the robustness that is exhibited, is mitigated according to the proposed scheme's Sleep-time estimations and assignments.

The structure of this work is as follows: Section II describes the related work done and the need in adopting a Traffic-based scheme, and then Section III follows presenting the proposed Backward Traffic Difference Estimation for Energy Conservation for Mobile opportunistic resource sharing. Section IV presents the real time performance evaluation results focusing on the behavioral characteristics of the scheme and the Backward Traffic Difference along with the system's response, followed by Section V with the conclusions and foundations, as well as potential future directions.

II. RELATED WORK

Many recent high-quality measurement studies [1-5] have convincingly demonstrated the impact of Traffic on the end-to-end connectivity [6], and thus the impact on the Sleep-time duration and the EC. The realistic traffic in Real-Time communication networks and multimedia systems, including wired local-area networks, wide-area networks, wireless and mobile networks, exhibits noticeable burstiness over a number of time scales [8] [9] and [10]. This fractal-like behavior of network traffic can be much better modeled using statistically self-similar or Long Range Dependent (LRD) processes, which, have significantly different theoretical properties from those of the conventional Short Range Dependent (SRD) processes. There are many Sleep-time scheduling strategies that model the node transition between ON and OFF states. Existing scheduling strategies for wireless networks could be classified into three categories: the coordinated sleeping [11] [12], where nodes adjust their sleeping schedule, the random sleeping [13] and [14], where there is no certain adjustment mechanism between the nodes in the sleeping schedule with all the pros and cons [15], and on-demand adaptive mechanisms [16], where nodes enter into Sleep-state depending on the environment requirements whereas an out-band signaling is used to notify a specific node to go to sleep in an on-demand manner.

In addition to the existing architectures, a fertile ground of the development of new approaches has been the association of different parameters with communication mechanisms in order to reduce the Energy Consumption. These mechanisms can be classified into two categories: Active and passive schemes. Active techniques conserve energy by performing energy conscious operations, such as transmission scheduling and energy-aware routing. Mavromoustakis in [2] considers the association of EC problem with different parameterized aspects of the traffic (like traffic prioritization) and enable a mechanism that tunes the interfaces' scheduler to sprawl in the sleep state according to the activity of the traffic of a certain node in the end-to-end path.

The main goal of the proposed scheme is to minimize the energy consumption using the incoming Traffic that is destined onto each one of the nodes, taking into consideration the repetition pattern of the Traffic. The scheme then estimates the Backward Difference for extracting the time duration for which the node is allowed to Sleep during the next time slot *T*. This mechanism, in order to enable further recoverability and availability of the requested resources, proposes an efficient way to cache the packets destined for the node with turned-off interfaces (sleep state) onto intermediate nodes and enables, through the Backward Traffic Difference estimation, the next Sleep-time duration of the recipient node to be adjusted accordingly.

III. BACKWARD DIFFERENCE TRAFFIC ESTIMATION FOR ENERGY CONSERVATION FOR MOBILE PEER-TO-PEER OPPORTUNISTIC RESOURCE SHARING

The input nodal traffic is being considered in this work and estimated according to the Backward Traffic Difference (BTD). Wireless nodes, even if they are acting in the network as intermediate forwarding nodal points or as destinations, they have to be self-aware in terms of power and processing as well as in terms of accurate participation in the transmission activity. There are many techniques such as the dynamic caching-oriented methods. The present work utilizes a hybridized version of the proposed adaptive dynamic caching [2], which is considered to behave satisfactorily and enables simplicity in real time implementation [3]. On the contrary with [3][4], in this work a different real-time mobility scenario is modeled and hosted in the scheme, which, enables an adaptive tuning of the Sleep-time duration according to the activity of the Traffic on each node.

The following section presents the estimations performed on each node in order to evaluate the next Sleep-time duration according to the node's incoming activity by using the BTD mechanism.

A. *Backward Difference Traffic Estimation for Energy Conservation*

The proactive activity scheduling may increase the network lifetime, contrarily with periodic Sleep-Wake schedules, as it enables dissimilar active-time. The nodes are set in the active state for a period of time according to the incoming traffic. The activity period(s) of a node is primarily dependent on the nature and the spikes of the incoming traffic destined for this node [6]. If the transmissions are performed on a periodic basis then the nodes' lifetime can be forecasted and according to a model can be predicted and estimated [7]. This work introduces the Backward Traffic Difference (BTD) estimation in order to associate the traversed traffic of a node with the previous moments and, in real-time, reduce the redundant Activity-periods of the node in order to conserve energy. Figure 1 shows in Real-time the Incoming traffic that a node experiences with the associated traffic capacity and activity duration of the node. The traffic can be seen as a renewal process [7] that has aggregation characteristics [9] from different sources.

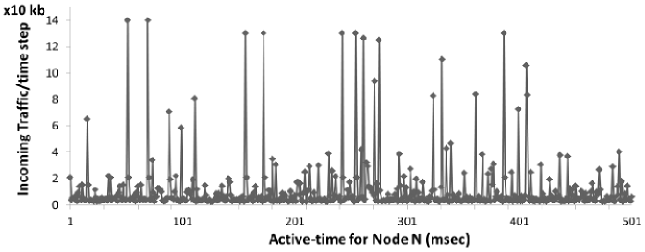

Figure 1. Real-time Incoming traffic that a node experiences with the associated traffic capacity and activity duration of the node with mean $E(A_{t_f})$.

This work assigns a dissimilar sleep and wake time for each node, based on traffic that is destined for each node which, is cached onto 1-hop intermediate node(s), during the sleep time duration. Figure 2 shows that, in a pre-scheduled periodic basis, nodes can be in the Sleep-state. Likewise, the packets that are destined for the certain node can be cached for a specified amount of time (as long as the Node (i) is in the Sleep-state) in the 1-hop neighbor node (Node(i-1)) in order to be recoverable when node enters the Active state.

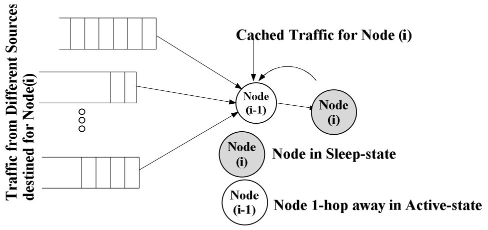

Figure 2. A schematic diagram of the caching mechanism addressed in this work.

The 1-hop neighbor node (*Node(i-1)*) is selected to cache the packets destined for the node with turned off interfaces (sleep state). The principle illustrated in Figure 2 denotes that, when incoming traffic is in action for a specific node then the node remains active for prolonged time. As a showcase this work takes the specifications of the IEEE 802.11x that are recommending the duration of the forwarding mechanism that takes place in a non-power saving mode lays in the interval *1 nsec < τ <1 psec*. This means that every ~0.125μsec (8 times in a msec) the communication triggering action between nodes may result a problematic end-to-end accuracy. Adaptive Dynamic Caching [2] takes place and enables the packets to be "cached" in the 1-hop neighboring nodes. Correspondingly, if node is no-longer available due to sleep-state in order to conserve energy (in the interval slot *T=0.125μsec*), then the packets are cached into an intermediate node with adequate capacity equals to: $C_{t_f,k(s)}(t) > C_{t_f,i}(t)$, where $C_{t_f} > \alpha \cdot C_i$; where α_i is the capacity adaptation degree based on the time duration of the capacity that is reserved on node N of C_k ; where $C_{t_f,k(s)}(t)$ is the needed capacity where i is the destination node and k is the buffering node (a hop before the destination via different paths).

As this scheme is entirely based on the aggregated self-similarity nature of the incoming traffic with reference to a certain node, there should be an evaluation scheme in order to enable the node to Sleep, less or more according to the previous activity moments. This means that, as more as the cached traffic is, there is an increase in the sleep-time duration of the next moment for the destination node. This is indicated in the following scheme which, takes into account the Self-Similarity to estimate the potential spikes of the Sleep-time duration. The Sleep-time in turn decreases or increases accordingly, based on the active Traffic destined for *Node(i)* while being in the Sleep-state.

1) Backward Difference Traffic Moments and Sleep-time duration estimation

Let $C(t)$ be the capacity of the traffic that is destined for the Node *i* in the time slot (duration) *t*, and $C_{N_i(t)}$ is the traffic capacity that is cached onto *Node (i-1)* for time *t*. Then, the one-level Backward Difference of the Traffic is evaluated by estimating the difference of the traffic while the *Node(i)* is set in the Sleep-state for a period, as follows:

$$\begin{aligned} \nabla C_{N_i(1)} &= T_2(\tau) - T_1(\tau-1) \\ \nabla C_{N_i(2)} &= T_3(\tau-1) - T_2(\tau-2) \\ &\vdots \\ \nabla C_{N_i(n+1)} &= T_n(\tau-(n-1)) - T_2(\tau-(n-2)) \end{aligned} \qquad (1)$$

where $\nabla C_{N_i(1)}$ denotes the first moment traffic/capacity difference that is destined for *Node(i)* and it is cached onto Node (i-1) for time τ , $T_2(\tau) - T_1(\tau-1)$ is the estimated traffic difference while packets are being cached onto *(i-1)* hop for recoverability. Equation (1) depicts the BTD estimation for one-level comparisons, which means that the moments are only being estimated for one-level ($T_2(\tau) - T_1(\tau-1)$). The Traffic Difference is estimated so that the next Sleep-time duration can be directly affected according to the following:

$$\delta(C(T)) = C_{total} - C_1, \forall C_{total} > C_1, T \in \{\tau-1, \tau\} \qquad (2)$$

where the Traffic that is destined for *Node(i)*, urges the Node to remain active for $\frac{\delta(C(T))}{C_{total}} \cdot T_{prev} > 0$.

The load generated by one source is mean size of a packet train divided over mean size of packet train and mean size of inter-train gap or it is the mean size of ON period over mean size of ON and OFF periods as follows:

$$L_i = \frac{\overline{ON_i}}{\overline{\overline{ON_i} + \overline{OFF_i}}} \qquad (3)$$

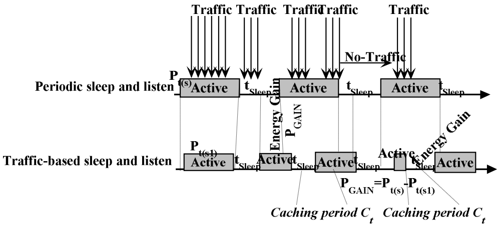

Figure 3. ON and OFF periodic durations of a Node with the associated cached periods.

When a node admits traffic, the traffic flow t_f , can be modeled as a stochastic process [17] and denoted in a cumulative arrival form as $A_{t_f} = \{A_{t_f}(T)\}_{T \in N}$, where $A_{t_f}(T)$ represents the cumulative amount of traffic arrivals in the time space [0..T]. Then, the $A_{t_f}(s,T) = A_{t_f}(T) - A_{t_f}(s)$ (4), denotes the amount of traffic arriving in time interval (*s, t*]. Hence the next Sleep-time duration for *Node (i)* can be evaluated as:

$$L_i(n+1) = \frac{\delta(C(T) \mid A_{t_f}(s,T))}{C_{total}} \cdot T_{prev}, \forall \delta(C(T)) > 0 \qquad (5)$$

For the case that the $\delta(C(T)) < 0$ it stands that:

$\delta(C(T)) = C_{total} - C_1, \forall C_{total} < C_1, T \in \{\tau-1, \tau\}$, and $\frac{\delta(C(T))}{C_{total}} \cdot T_{prev} < 0, \forall T_{prev} > T_{prev}(\tau-1)$, the $C_{N_i} < 0$ and the total active time increases gradually according to the following estimation:

$$T_{sleep} = T(\tau - t_1) - (-C_{N_i}) = T(\tau - t_1) + T_{C_{N_i}} \qquad (6)$$

where the $T_{C_{N_i}}$ is the estimated duration for the capacity difference for $C_{N_i} < 0$, whereas the Sleep-time duration decreases accordingly with Equations (5) and (6), iff the $C_{N_i} < 0$. Considering the above estimations the Traffic flow can be expressed as in [19] as

$$A_{t_f}(T) = m_{t_f}(T) + \hat{Z}_{t_f}(T) \qquad (7)$$

where $m_{t_f}(T)$ is the mean arrival rate and $\hat{Z}_{t_f}(T) = \sqrt{a_{t_f} m_{t_f}(T)} \cdot \hat{Z}_{t_f}(T) \cdot a_{t_f}$. The coefficient a_{t_f} is the variance coefficient of $A_{t_f}(T)$. $\hat{Z}_{t_f}(T) \cdot$ is the smoothed mean as in [17], and with $\mathrm{E}(\hat{Z}_{t_f}(T)) = 0$ satisfying the following variance and covariance functions:

$$\begin{aligned} v_{t_f} &= a_{t_f} m_{t_f} \cdot T^{2H_{t_f}} \\ \sigma_{t_f}(s,T) &= \frac{1}{2} a_{t_f} m_{t_f} \cdot (T^{2H_{t_f}} + s^{2H_{t_f}} - (T-s)^{2H_{t_f}}) \end{aligned} \tag{8}$$

where $H_{t_f} \in \left[\frac{1}{2}, 1\right]$ is the *Hurst* parameter, indicating the degree of self-similarity. Estimations in (8) can only be valid if the capacity of the *Node (i-1)* can host the aggregated traffic destined for *Node (i)* satisfying the $\sup_{s \le T} \left\{ \sum_{t_f=1}^{N} A_{t_f}(s,T) - C_{t_f}(T) \right\}$, for traffic flow t_f at time T and $C_{t_f}(T)$ represents the service capacity of the *Node(i-1)* for this time duration.

The basic steps of the proposed scheme can be summarized in the pseudocode of the Table 1.

```
for Node(i) that there is $C(t)$>0 {
  while ($C_{N_i(t)}$>0) { //cached Traffic measurement
    Evaluate ($\nabla C_{N_i(1)}$);
Calc($\delta(C(T)) = C_{total} - C_1, \forall C_{total} > C_1, T \in \{\tau - 1, \tau\}$)
if (Activity_Period=$\frac{\delta(C(T))}{C_{total}} \cdot T_{prev}$>0)
//Measure Sleep-time duration
$L_i(n+1) = \frac{\delta(C(T) \mid A_{t_f}(s,T))}{C_{total}} \cdot T_{prev}, \forall \delta(C(T)) > 0$
else if ($\delta(C(T)) < 0$)
   $T_{sleep} = T(\tau - t_1) - (-C_{N_i}) = T(\tau - t_1) + T_{C_{N_i}}$;
   Sleep ($T_{sleep}$);
     } //for
}//while
```

Table 1. Basic steps of the proposed BTD scheme.

Taking into consideration the above stochastic estimations, the Energy Efficiency EE_{t_f} can be defined as a measure of the capacity of the *Node(i)* over the *Total Power consumed* by the *Node*, as:

$$EE_{t_f}(T) = \frac{C_{t_f}(T)}{TotalPower} \tag{9}$$

Equation 9 above can be defined as the primary metric for the lifespan extensibility of the wireless node in the system.

IV. REAL TIME PERFORMANCE EVALUATION ANALYSIS, EXPERIMENTAL RESULTS AND DISCUSSION

In this section, we demonstrate the effectiveness of the proposed BTD approach by using the MICA2 sensors nodes [20]. Nodes are configured to be manipulated as Peer devices hosting the proposed BTD scheme. These sensors were equipped with the MTS310 sensor boards. The MICA2 features a low power processor and a radio module operating at 868/916 MHz enabling data transmission at 38.4Kbits/s with an outdoor range of maximum set to 50 meters-taking no fading obstacles in-between for better and clearer signal strength. The TinyOS operating system is hosted onto MICA2 using the Nested C (NesC) language. A dynamic topology with the mobility expressed in Section IV.A is implemented, where the BTD scheme assigns the Traffic-oriented Sleep and Wake durations. In the evaluation of the proposed scheme we took into account the signal strength measures as developed in [2] and [3] and the minimized ping delays between the nodes in the end-to-end path. The underlying communication supports the Cluster-based Routing Protocol (CRP) [21]. A common look-up application is being developed to enable users to share resources on-the-move which, are available by peers for sharing. This application hosts files of different sizes that are requested by peers in an opportunistic manner.

A. Mobility Model used for mobile peers

In the proposed scenario the new speed and direction are both chosen from predefined ranges, [v_{min}, v_{max}] and [0, 2π), respectively [17] and [18]. The new speed and direction are maintained for an arbitrary length of time, randomly chosen from (0, t_{max}]. At the end of the chosen time, the node makes a memoryless decision of a new random speed and direction. The movements are expressed as a Fractional Random Walk (FRW) on a Weighted Graph [22].

B. Real-time performance testing and evaluation using the MICA2 sensors equipped with the MTS310 sensor boards

In this section, we present the results extracted after conducting the real time evaluation runs of the proposed scenario. In the utilized scenario we have used 30 nodes with each link (frequency channel) having max speed reaching data transmission at 38.4Kbits/s. The wireless network is organized in 6 overlapping clusters which, may vary in time in the active number of the nodes. Each source node transmits one 512-bytes (~4Kbits-light traffic) packet asynchronously and randomly each node selects a destination. The speed of each device can be measured with the resultant direction unit vector [3] and the speed. Each device has an asymmetrical storage capacity compared with the storages of the peer devices. The range of the capacities for which devices are supported are in the interval 1MB to 20MB.

Figure 4 shows the fraction of the remaining Energy through time in contrast to the comparison and evaluation extracted for different schemes during the real-time experimentation. As all schemes aim to reduce the Energy consumption, the proposed scheme behaves satisfactorily in contrast to the scheme developed in [6]. Figure 5 shows the Successful packet Delivery Ratio (SDR) in regards to the simultaneous requests in the intra-cluster communicating path, for both statically located nodes (no movement) and mobile nodes. Figure 6 shows the Average

Throughput with the Total Transfer Delay in (μsec) is shown, for different mobility models. Figure 6 depicts the different Throughput responses that the proposed scheme exhibits in contrast to the mobility characteristics, for full node mobility, moderate and low (30%) mobility.

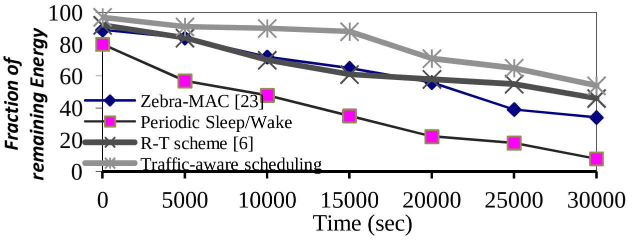

Figure 4. The fraction of the remaining Energy through time using real-time evaluation for different schemes.

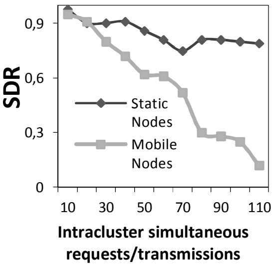

Figure 5. The Successful packet Delivery Ratio (SDR) with the simultaneous requests.

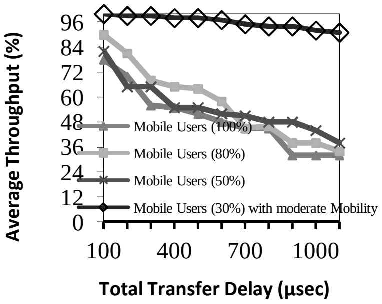

Figure 6. The Average Throughput with the Total Transfer Delay (μsec).

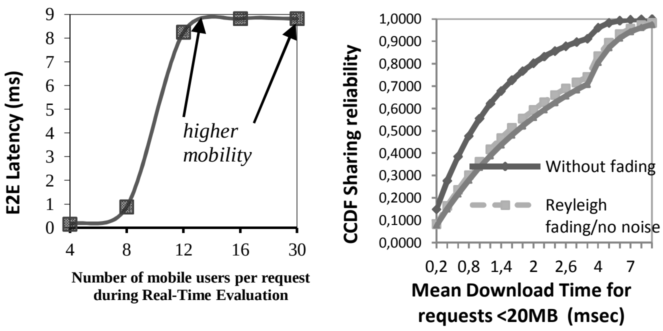

Figure 7. The End-to-End Latency with the number of requests for the users during Real-Time evaluation; and the CCDF for the Sharing Reliability with the Mean download Time for requests over a certain capacity.

The End-to-End Latency with the number of requests for the users during Real-Time evaluation is shown in Figure 7 indicating the number of users that are utilized in the presence of high mobility. Likewise, Figure 7 shows the respective Complementary Cumulative Distribution Function (CCDF or simply the tail distribution) with the Mean download Time for requests over a certain capacity. The later results were extracted in the presence of fading and no-fading communicating obstacles. Figures in 8 show the network lifetime with the number of Mobile Nodes; and the Throughput response of the system hosting the proposed scheme with the Number of requests for certain fading evaluated characteristics.

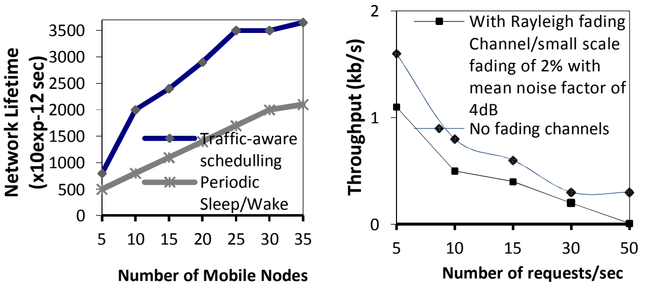

Figure 8. Network Lifetime with the Number of Mobile Nodes; and the Throughput response of the system hosting the proposed scheme with the Number of requests for certain fading measures' characteristics.

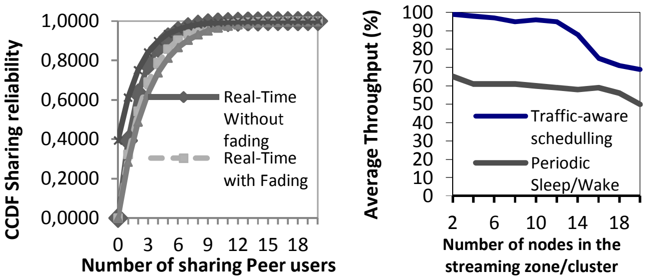

Figure 9. CCDF Sharing Reliability with the Number of sharing Peer-users; and the Average Throughput with the number of Nodes in the streaming zone.

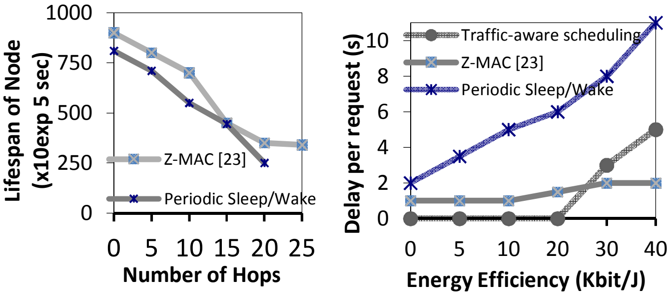

Figure 10. Lifespan of each node with the number of hops for different schemes Real-Time comparisons; and the measures for the Delay requests with the corresponding Energy efficiency.

Results obtained presented in Figure 9, show the CCDF Sharing Reliability with the Number of sharing Peer-users; and the Average Throughput with the number of Nodes in the streaming zone. The results extracted for CCDF Sharing Reliability with the Number of sharing Peer-users, were for both Simulation experiments and Real-Time estimations so that there is a comparison axis between the simulated results and the results extracted from Real-Time Traffic and experiments. In addition, the Average Throughput in contrast to the number of Nodes in the streaming zone was evaluated in Real-Time using periodic and the proposed scheme. It is undoubtedly true that the proposed scheme enables higher Average Throughput response in the system, whereas comparing with the results extracted from Figure 4, the proposed scheme enables greater network lifetime by using this activity Traffic-based scheme. Figures in 10, show the Lifespan of each node with the number of hops for different schemes Real-Time comparisons; and the measures for the Delay requests with the corresponding Energy efficiency. Results in Figure 10 show that the network lifetime can be significantly prolonged when the

BTD is applied, in contrast with the results obtained in Real-Time experiments for the [23] and for the periodic Sleep/Wake scheduling.

V. CONCLUSIONS AND FURTHER RESEARCH

This work considers the BTD scheme hosted on wireless nodes during the resource exchange process. This research proposes and examines a backward estimation model for allocating -upon estimation- the time-duration that a node is allowed to sleep (according to the traversed traffic) so that it conserves Energy. The scheme uses the cached mechanism for guaranteeing the requested resources and a model for the Sleep time estimation based on the incoming Traffic that traverses the nodes. According to the Real-Time results extracted, the designed model guarantees the end-to-end availability of requested resources while it reduces significantly the Energy Consumption, while it maintains the requested scheduled transfers. Performance evaluation and the results extracted in Real-Time show that this method uses optimally the network's and system's resources in terms of capacity and EC and offers high SDRs particularly in contrast with other similar existing Energy-efficient methods. Next steps and on-going work within the current research context will be the expansion of this model into a Multi-level Markov Fractality Model so that it associates the different moments of the Traffic activity and it will be able to extract the Sleep-time estimations for the nodes, in order to enable them to conserve Energy, while maintaining the resource sharing process on-the-move.

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