On the Real-Time Evaluation of Two-Level BTD Scheme for Energy Conservation in the Presence of Delay Sensitive Transmissions and Intermittent Connectivity in Wireless Devices

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Abstract—**This work elaborates on the real-time implementation and comparative evaluation of an Energy-efficient scheme for sharing resources using the MICA2dot wireless nodes/motes. The proposed scheme allows the nodes to sleep adaptively according to the volume of incoming traffic, offering Energy Conservation (EC) to the moving nodes. Nodes that are exchanging delay sensitive/constrained resources apply the one-level Backward Traffic Difference (BTD) scheme or the *two-level BTD,* according to delay transmission and capacity criteria, in order to enable nodes to sleep, based on their activity and their admitted traffic. The incoming traffic impacts the Sleep-time duration of the node by using traffic's backward difference in order to define an adaptive Sleep-time duration for each node. The proposed scheme is being evaluated through real-time implementation by using MICA2dot wireless motes, which are exchanging resources in a Mobile Peer-to-Peer manner using certain motion pattern. Performance evaluation and the extracted results validate the scheme's efficiency for minimizing the Energy Consumption in real-time. In addition, comparative performance evaluations with other similar schemes show the efficiency of the proposed research approach. The framework of this paper maximizes further the efficiency and reliability of the resource exchange process of the nodes, while it minimizes the Energy consumption.**

Keywords- energy conservation scheme; lifespan extensibility metrics; one-level BTD scheme; selective two-level BTD scheme; traffic-oriented energy conservation; traffic volume and capacity metrics

I. INTRODUCTION

In recent years, the number of wireless network deployments for real-time applications, including individual and global industrial applications, has rapidly increased. As a variety of device-dependent applications were born, the necessity for developing a scheme for conserving energy becomes even more timely. Wireless nodes communicate over error-prone wireless channels with limited battery power, vulnerable reliability and through deployed energy-hungry applications. These characteristics of wireless nodes make the design of resource exchange schemes challenging. However, with mobility many inherent problems follow such as the resource scarceness, finite energy for the wireless nodes and low connectivity whereas, mobile nodes demand high levels of responsiveness that in turn, demand resource intensive computing resources. Wireless devices in order to conserve energy switch their states between Sleep mode, Wake mode and idle mode. This is reflected to the responsiveness of the underlying applications and processes hosted by these devices, which are 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. Due to wireless resources' scarceness, 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 elaborates on the capabilities of the backward estimation model for extracting the time-oriented differential traffic, in contrast to the nodal characteristics of the wireless device in time. The proposed work exploits the model proposed in [1] and utilizes the resource availability and capacity characteristics in a reflected model for offering Energy Conservation and minimization of scarcity of the requested resources. The proposed scheme uses the cached mechanism (as in [1]) for guaranteeing the requested resources which are delay sensitive, whereas wireless nodes are subject to sudden failures. The proposed mechanism extends the introduced Backward Traffic Difference (BTD) scheme [1], by adding a second level of traffic difference in the proposed framework-namely two-level BTD. 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 and cluster-based communication. Furthermore, since each node has different capacity measures and undefined remaining energy, this work adopts a differential dissimilar assignment(s) of sleep-wake schedule estimation, based on the traffic difference through time and the relative capacity and the associated traffic characteristics. The proposed model has been applied in real-time devices and the conducted experiments using various capacity and traffic-aware metrics, were carried-out for the energy conservation and the evaluation of the proposed model. The BTD scheme initially evaluates the data volume/traffic and according to the delay bound/limitations, the model adds a second level of traffic difference. 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 supporting delay sensitive data transfers.

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 by presenting the proposed Backward Traffic Difference estimation for Energy Conservation as in [1]. The proposed framework makes progress beyond the current state of the art by supporting delay bounded/sensitive data transfers in collaboration with the promiscuous caching recoverability mechanism in the case of intermittent connectivity. 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 and Motivation

Multimedia or delay-sensitive applications can only be implemented with guaranteed QoS and QoE support, in wired environments whereas, rarely mobile devices can guarantee the communication in an end-to-end reliable manner. This is primarily the reason that the number of applications beyond file sharing is kept on a low implementation level [2], despite the penetrative character of Peer-to-Peer systems nowadays. The type of application hosted on wireless devices typically relies its presence on the energy that the device hosts. Recent research has addressed the Mobile Peer-to-Peer (MP2P) connectivity from different perspectives. Work done in [3] has introduced a middleware support for client-server architectures in nomadic environments, where in an organized way the terminals take into consideration the group-oriented characteristics. In these environments, the associated RPC-based middleware mechanisms have been enhanced with queuing or buffering capabilities in order to cope with intermittent connections. Examples of these implementations are introduced in Mobile DCE in researches [4], [5], [6] and [7] including diffusion policies and resources' processing [4] and [5] and manipulation as well as different replication procedures [6] and [7].

Moreover, many recent high-quality design and validation measurement studies in [8], [9] have convincingly demonstrated the impact of traffic on the end-to-end connectivity (like the work in [10]) 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 [11] and [12]. This fractal-like behavior of network traffic can be much better modeled by using statistically self-similar or Long Range Dependent (LRD) processes. These processes can be further improved in terms of estimations, taking into consideration different theoretical properties from those of the conventional Short Range Dependent (SRD) processes. There are many Sleep-time scheduling strategies that model each node's transition between *ON* and *OFF* states. Existing scheduling strategies for wireless networks could be classified into three categories: the coordinated sleeping [13], [14], where nodes adjust their sleeping schedule, the random sleeping [15] and [16], where there is no certain adjustment mechanism between the nodes in the sleeping schedule with all the pros and cons as expressed in [17], and on-demand adaptive mechanisms [18], 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 number of researches have attempted the association of different parameters with communication mechanisms, in order to reduce the energy consumption. These researches have been introduced in [1], [8], [9] and [19] where different traffic-based manipulations are modeled, in order to overcome the over-exposure and over-activity of nodes. These traffic-aware mechanisms can be classified into two categories: active and passive schemes. Active techniques conserve energy by performing energy conscious operations, such as traffic and data volume transmission scheduling by using a directional antenna [20], and energy-aware routing [21]. On the other hand, passive techniques conserve energy by scheduling the interfaces of the devices to the sleep mode when a node is not currently taking part in communication activity [22] and host different adaptive methodologies like the Adaptive-Traffic enabled methodologies [9], [10]. The latter takes into consideration the traffic pattern that a node is experiencing as incoming and outgoing traffic. Authors in [17] consider 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. Authors in [18] aim to minimize energy consumption in Wireless Sensor Networks (WSNs) through a 2-tier asynchronous scheduling scheme for delay constrained connectivity in wireless devices that are asymmetrical in terms of capacity and battery lifetime.

Within the context of providing an energy-efficient traffic manipulation, a fertile ground has been the idea of the development of new heuristic approaches, by associating different traffic-aware (transmission-aware) parameters with communication mechanisms for reducing the Energy Consumption. In this context, the main goal of this work is to further minimize the energy consumed by the wireless nodes by applying further traffic association and stationarity measures to the estimated sleep-time duration of the node. This work aims at prolonging further the network lifetime by minimizing the energy consumption. This is performed through the incoming traffic that traverses each one of the nodes, taking into consideration the repetition pattern of the traffic. In addition, with the work done in [1], the proposed scheme estimates the Backward Difference by using a second level of traffic difference estimation, for extracting the time duration for which the sensor mote (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. The model has been applied to MICA2 sensor nodes hosting a TinyOS operating system which has been programmed to tune the wireless interfaces of the motes using the Nested C (NesC) language. The designed model and the real-time conducted experimental results, show that the proposed scheme 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.

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

Sleep/wakeup schemes can be classified into three main categories namely: on demand, asynchronous and the methodologies based on the scheduled rendezvous. On-demand schemes assume that destination nodes can be awakened somehow just before receiving data. As traffic-aware policy requires an active scheme to be applied and reflective solutions to be adopted, this work uses the time-based incoming traffic to minimize the energy consumption and the relative trade-offs while prolonging the systems' lifetime. The scheduled rendezvous for assigning the independent sleep/wakeup slots requires that nodes in the system are synchronized and neighboring nodes wake up and communicate at the time that at least 1-hop neighbor is awake and informed. In this work the input nodal traffic is being considered and manipulated according to the BTD. This manipulation is the basis for providing using a feedback model, the sleep-time duration estimation to nodes. Wireless nodes 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 [9], which is considered to behave satisfactorily and enables simplicity in real time implementation [10]. On the contrary with [10] [19], 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 and the second level of BTD estimation to extract the time duration for which the node is allowed to Sleep during the next time slot *T*.

A. Backward Difference Traffic Estimation for Energy Conservation for delay sensitive transmissions

Taking into account the fact that opportunistically connected nodes are dynamically changing their operational characteristics, when a source needs to send requested packets or stream of packets (file) to a destination where the destination node(s) may have moved or is/are set in the Sleep-state, then the requested information will be missed and lost. This implies that, in a non-static multi-hop environment, there is a need to model the activity slots that a node experiences in contrast to the requested resources in the end-to-end path such that the resources can be efficiently shared among users whereas, any redundant transmissions and lost packets/streams are avoided.

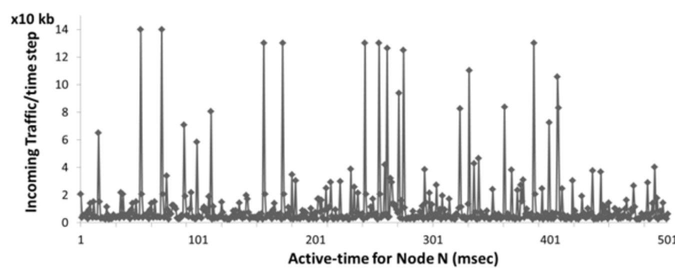

Figure 1. Real-time Incoming traffic that a node experiences with the associated traffic capacity and activity duration of the node with mean $E(A_{t_f})$.

As appropriate mechanisms are required to guide the activity periods of each one of the nodes, the traversed traffic can be the parameterized input. In this way, it evaluates the next Sleep-time or the Active periods, and considers the terminal's transmission and reception durations. This can be achieved through the BTD estimation. The proactive 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]. In this framework, this work introduces the one-level BTD and the second level of 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 the incoming traffic that a node experiences in real-time 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.

This work primarily 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 of the destination node. 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.

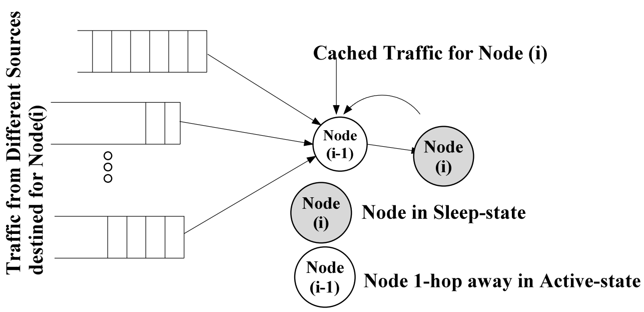

Figure 2. A schematic diagram of the caching mechanism addressed in this work.

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 that takes into account the Self-Similarity to estimate the potential spikes of the Sleep-time duration. The Sleep-time in turn accordingly decreases or increases, 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

In [1], authors expanded the traffic-oriented Sleep and Wake durations by using single moment Backward Traffic Difference and exploiting the silent periods to estimate an increase of the sleep-time duration and conserve energy. Further to the work done in [1], this work evaluates the second level of BTD by using a statistical mean in the evaluation of the duration of the next sleep-time of the node. 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:

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

$\nabla C_{N_i(1)}$ 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:

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

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

According to [9], the Long-Range Dependence of self-similar incoming traffic can be measured using the probability density function of the Pareto distribution and the corresponding mean value, whereas, 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

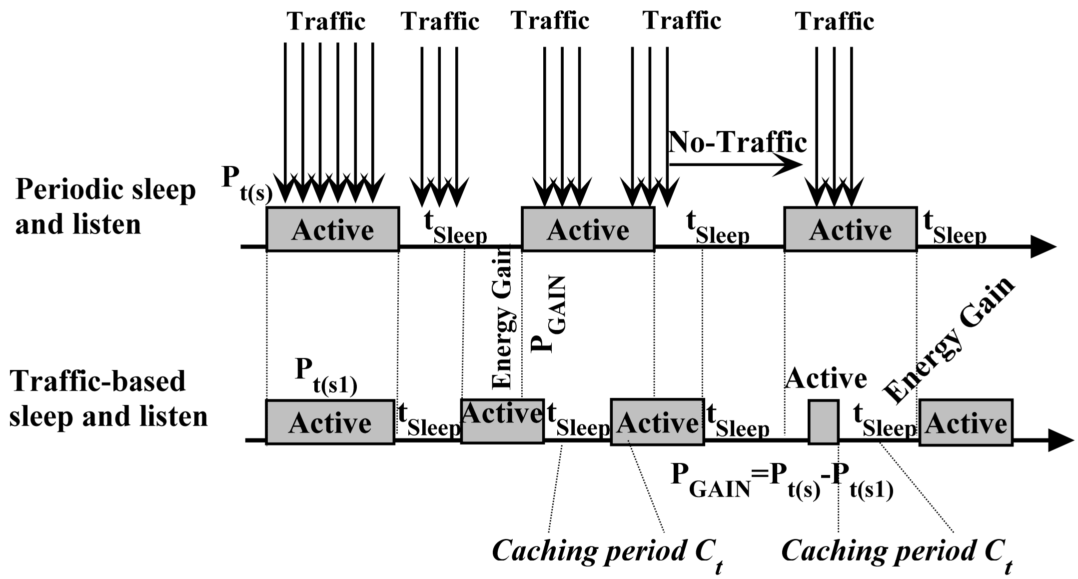

Figure 3. *ON* and *OFF* periodic durations of a Node with the associated cached periods.

or it is the mean size of *ON* period over mean size of *ON* and *OFF* periods as follows:

$$L_i = \frac{ON_i}{ON_i + OFF_i} \tag{3}$$

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:

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

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

$$\delta(C(T)) = C_{total} - C_1, \forall C_{total} < C_1, T \in \{\tau - 1, \tau\} \quad ,$$

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:

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

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 [23] as

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

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

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

$H_{t_f} \in \left[\frac{1}{2}, 1\right]$ is defined as 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.

2) Two-level Backward Difference Traffic Moments and Sleep-time duration estimation

According to the one-level Backward Difference of the Traffic, the difference in the capacity measure can be estimated as the difference of the traffic while the Node (*i*) is set in the sleep-state. This corresponds to the admitted nodal traffic for a period, as the estimations of the one-moment traffic difference set above. Therefore, in order to estimate the second level Backward Traffic Difference, we need to associate the T_1, T_2, T_3 traffic moments with the volume of admitted traffic $\nabla C_{N_i(t)}$ and define the difference as follows:

$$\begin{aligned} \nabla C_{N_i(0)} &= T_3(\tau) - T_1(\tau-2) \\ \nabla C_{N_i(1)} &= T_2(\tau) - T_1(\tau-1) \\ \nabla C_{N_i(2)} &= T_3(\tau-1) - T_2(\tau-2) \end{aligned} \tag{9}$$

Figure 4 shows the two level traffic moments and the association between the T_1, T_2, T_3 traffic moments through the Backward slots that are associated with the traffic.

According to Equation (9) the second level Backward Traffic Difference defines the moments that a specified volume of traffic traverses the *Node(i)*. Therefore, the second level Backward Traffic Difference can impact the evaluated sleep duration if the traffic has increased or the sleep-time duration of the *Node(i)* has increased, by avoiding the node to become saturated [8], [9], [24] and [25]. This estimation after consecutive statistical mean estimations has been found to be an estimation of the time as:

$$L_i(n+1) = \frac{\nabla C_{N_i(0)} + \nabla C_{N_i(1)} + \nabla C_{N_i(2)}}{3 \cdot d_p} \tag{10}$$

or as a general form for the j-slot of a *Node(i)* as:

$$L_i^j(n+1) = \frac{\nabla C_{N_i(j-2)} + \nabla C_{N_i(j-1)} + \nabla C_{N_i(j)}}{3 \cdot d_p} \tag{11}$$

In (11), d_p is the maximum delay in the end-to-end path from a source to a destination where the reference (i.e., A) node lays in, T is the round/cycle for which t_{idle} is evaluated, and *n* is the number of hops. d_p is calculated as:

$$d_p = \sum_{i=0}^{i-1} \delta_i + T_i \tag{12}$$

δ_i is the duration where the requested data was hosted onto *i*-node, and T is the transmission delay.

In order to avoid node's capacity diversities and saturations, each node re-evaluates the sleep-time duration by applying idle listening slots. These slots occur when a sensor wireless node listens to an idle channel to receive possible traffic. Hence, in order to evaluate the idle time t_{idle} for each node that will get into the idle state, the following estimation takes place:

$$t_{idle} = \frac{(T - \max(d_p))}{n} \tag{13}$$

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

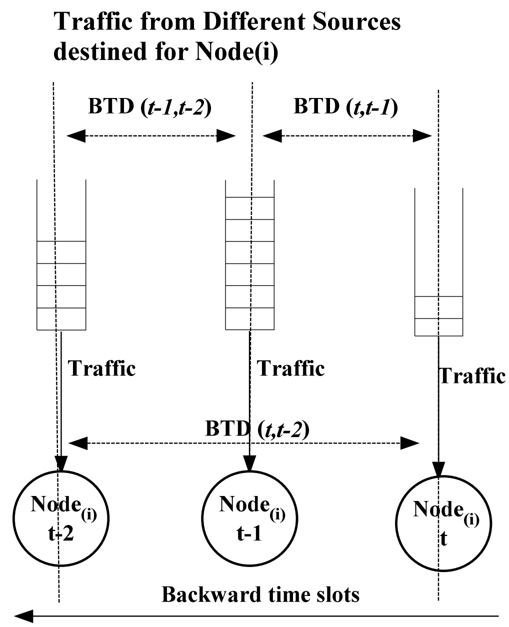

Figure 4. Two-level traffic moments for *node(i)* and the association between the T_1, T_2, T_3 nodal traffic moments.

TABLE I. BASIC STEPS OF THE PROPOSED TWO-LEVEL BTD SCHEME

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
Evaluate $L_i(n+1) = \frac{\delta(C(T) \mid A_{t_f}(s,T))}{C_{total}} \cdot T_{prev}, \forall \delta(C(T)) > 0$
else if ($C_{N_i(t)} > C_{N_i(t-1)}$){
while($t_{idle} = \frac{(T - \max(d_p))}{n}$){//Provided that t idle is satisfied

```
   //second level Backward Traffic
9: Evaluate  L_i^j(n+1) (∇C_{N_i(j-2)} + ∇C_{N_i(j-1)} + ∇C_{N_i(j)}) / (3·d_p)
   //Difference can impact the evaluated sleep
   duration,
   //according to the two-level BTD scheme
   proposed.

   }//if
   }//while
10: else if (δ(C(T)) < 0)
11:      T_sleep = T(τ - t_1) - (-C_{N_i}) = T(τ - t_1) + T_{C_{N_i}} ;
12: Sleep (T_sleep);
13: } //for
14: }//while
```

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:

$$EE_{t_f}(T) = \frac{C_{t_f}(T)}{TotalPower} \tag{14}$$

In addition, the Energy Efficiency should satisfy the minimum energy regions for wireless devices defined in [9] where the following is applied:

$$\arg\max(EE_{t_f}(T)) = \min\left[P_{thresshold}\right] \forall i, j \tag{15}$$

$P_{thresshold}$ is the consumed power in the resource interexchange region and should not exceed a certain threshold (as in [9]), and *i* and *j* are the streaming source and destination nodes respectively. Equations (14) and (15) 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, the effectiveness of the proposed BTD approach is demonstrated and the accuracy of the developed scheme is validated in real-time by comparing the analytical results of the scheme to those obtained from extensive simulation experiments in work done in [8],[9] and [10]. Towards evaluating the proposed scenario in real time, the MICA2 sensors nodes have been used [27] 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 both no-fading and fading obstacles in-between for better evaluation of the signal strength. The TinyOS operating system is hosted onto MICA2 using the Nested C (NesC) language. As the sensors are application-specific, they can only host a single application. TinyOS does not support memory management or internal process management and, therefore, it discourages applications from allocating or using dynamic memory. This feature enables to evaluate the trade-off between the periodic sleep-wake slot assignments and the proposed scheme which uses a variable and dynamic Sleep-slot assignment. 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. Furthermore, MICA2 supports an expansion connector for attaching various sensor boards on it. The MTS310 board was utilized, which supports a sensor board with a variety of sensing modalities including sounder and an overclocking alarm. The sounder was used to extract sound when needed and denoting the overload of the node or other determined functionalities. Towards evaluating the proposed scheme the signal strength measures were taken into account as developed in [8] and [9], as well as the minimized ping delays between the nodes in the end-to-end path according to the $d_p = Min\sum_{i=1}^{n} D_i$, where *D* is the delay from a node *i* to node *j*, and d_p is the minimized evaluated delay in the end-to-end available path. Moreover, considering the need of bandwidth and the limited battery power for wireless devices, it is necessary to apply efficient routing algorithms to create, maintain and repair paths, with least possible overhead production. The underlying radio technology supports the Cluster-based Routing Protocol (CRP) [28]. A common look-up application is being developed to enable users to share resources on-the-move that are available by peers for sharing. This application hosts files of different sizes that are requested by peers in an opportunistic manner.

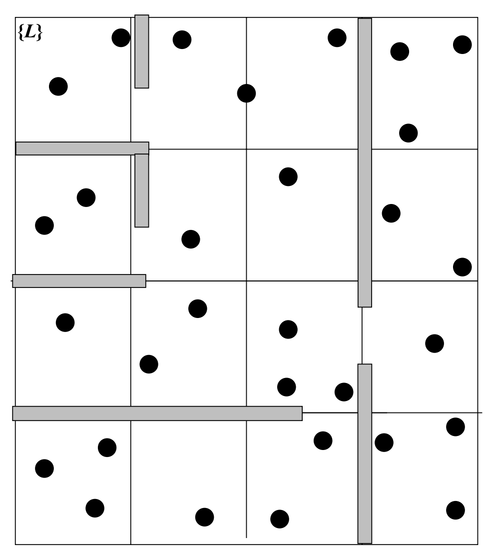

Figure 5. Topology and the location of the sensor nodes in the experimental room.

A. Mobility Model used for mobile peers

Unlike the predetermined Landscape in [31], in this work, the mobility scenario used is the Fractional Random Walk. The random walk mobility model was derived from the Brownian motion, which is a stochastic process that models random continuous motion [30], [31]. In this model, a mobile node moves from its current location with a randomly selected speed in a randomly selected direction as real time mobile users act. However, the real time mobility that the users express, can be defined by spotting out some environmental elements (obstacles, point-of-interest et.c) where users' decisions may be affected. In the proposed scenario, the new speed and direction are both chosen from predefined ranges, $[v_{min}, v_{max}]$ and $[0, 2\pi)$, respectively [1], [30]. 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, utilized in the same way as in [32]. The topology L and the sample location of the sensor nodes in the experimental room are shown in Figure 5. In addition, this work uses the Random walk as a Markov chain (designed as in the theoretical foundations in [30]) for the motion of each one of the nodes. This allows nodes to continue their path/journey according to their initial selection-decision from a point, i.e., A to a point B in L. By using the Random walk as a Markov chain model it denotes that the last step made by the random walk influences the next one based on the stationarity and the correlations between the movements. Under the condition that a node has moved to the right the probability that it continues to move in this direction is then higher than to stop movement. This leads to a walk adjusted to a walk mobility that leaves the starting point much faster than the original random walk model. The probabilities are defined as follows: assuming that a device is currently at location l_i, the next location of the node l_j is chosen from among the neighbors of i with probability:

$$p_{ij}^{L} = \frac{w_{ij}}{\sum_k w_{ik}} \tag{16}$$

Equation (16) presents the p_{ij} which should be proportional to the weight of the edge (l_i, l_j) and defines k as the destination location. In turn the sum of the weights of all edges in the landscape L is:

$$w^{L}{}_{ij} = \sum_{i,j:j>1} w_{ij} \tag{17}$$

All nodes have asymmetry in the signal strength and obstacles within their communication with other nodes whereas, they are moving with random walks. The mobility of each nodes is generated via mechanical robots using the Lynxmotion Track Robot Kit [35], which are programmed to follow the pattern of probabilistic Fractional Random Walk model. The control of the Robot is performed through a 2.4GHz Spectrum radio controller for the movements in all directions.

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

In this section, the results extracted after conducting the real time evaluation runs of the proposed scenario, are presented. In the utilized scenario, 30 nodes were used 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 [9] and the speed. Each device has an asymmetrical storage capacity compared with the storages of the peer devices. The ranges of the capacities for which devices are supported are set in the interval 1MB to 20MB[1].

Figure 6 shows the average Throughput in contrast to the number of nodes in the streaming zone that were evaluated in real-time using comparatively the periodic sleep-time durations, the scheme in [33] 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 7, the proposed scheme enables greater network lifetime by using the proposed activity traffic-based scheme. Moreover, Figure 8 shows the Successful packet Delivery Ratio (SDR) in regards to the simultaneous requests in the intra-cluster communicating path for the proposed two-level BTD scheme. The results extracted in Figure 8 are characterizing both statically located nodes (where no movement exists) and mobile nodes where Fractional Random Walk is applied. It is important to note that when the number of mobile nodes increases the SDR drops dramatically. After conducting controlled real-rime evaluations it was noticed that, the significant decrease in the SDR appears, if the total number of moving nodes exceeds the 60% of the nodes in the cluster. This is due to the promiscuous caching policy that it affects the active nodes to prolong their active-time duration causing thereafter to prolong their sleep-time duration which in turn, results in a significant drop in the SDR. Figure 9 shows the Average Throughput with the Total Transfer Delay in (μsec) is shown, for different mobility models. Figure 9 presents the different Throughput responses that the proposed scheme exhibits in contrast to the mobility characteristics, for full node mobility, moderate and low (30%) mobility. It is important to mark that in the cases of full node and moderate mobility, the Throughput decreases when the delays experienced are increased. This is expected, as when the delays on nodes increase the overall

[1] The capacity for each device can be tuned according to the volume of the Traffic in the configuration process.

cluster throughput drops. This is due to the transfers' end-to-end delay metric that characterizes the sensitivity of the transfer in delay.

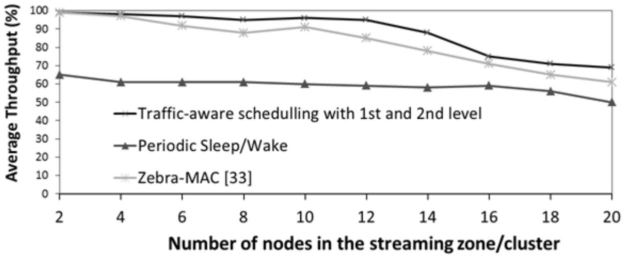

Figure 6. The average Throughput with the number of nodes in the cluster zone for delay bounded transmissions. Evaluation takes place for different comparable schemes.

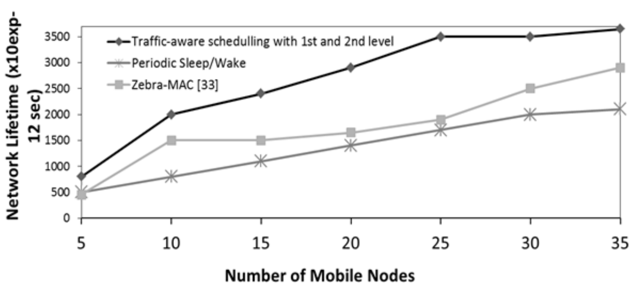

Figure 7. The fraction of the remaining Energy through time using real-time evaluation for different schemes.

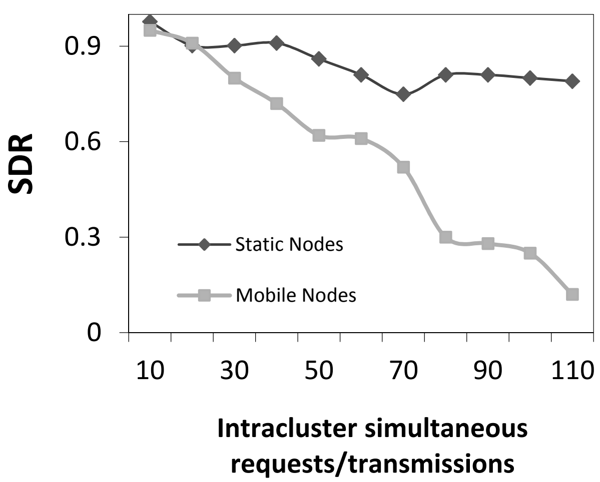

Figure 8. The Successful packet Delivery Ratio (SDR) with the simultaneous requests for the proposed two-level BTD scheme.

Figure 10 shows the lifespan of each node with the number of hops for different schemes provided by Real-Time evaluated comparisons. Measures for the Delay requests with the corresponding Energy efficiency are presented in Figure 11. Results obtained in Figure 11 show that the network lifetime can be significantly prolonged when the 2nd level BTD is applied. By comparing the results obtained through real-time experiments for the scheme developed in [33] as well as with the periodic Sleep/Wake scheduling, the proposed scheme offers greater Energy-Efficiency, while it minimizes the delay per request.

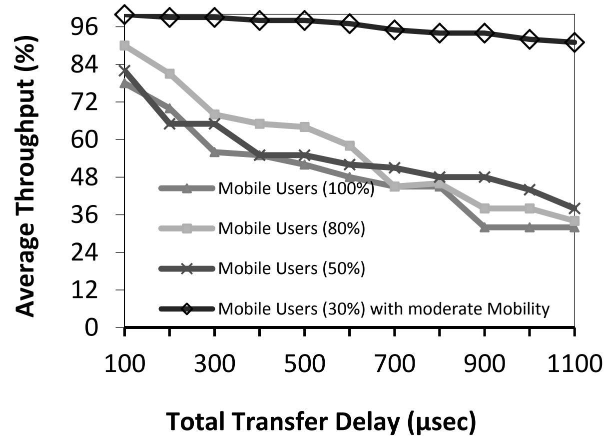

Figure 9. The Average Throughput with the Total Transfer Delay (μsec).

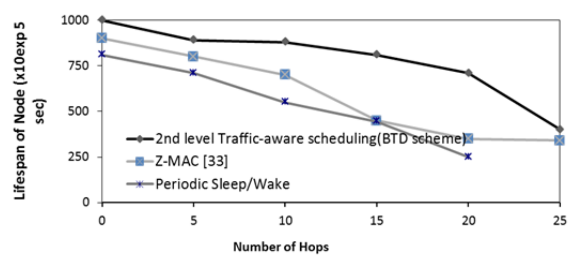

Figure 10. Lifespan of each node with the number of hops using different schemes under real-time evaluations.

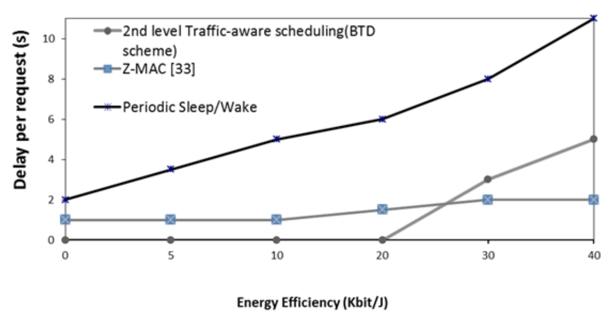

Figure 11. Evaluations for the delay requests with the corresponding Energy efficiency.

Figure 12 shows the fraction of the remaining Energy through time, in contrast to the comparison for different schemes and the associated evaluations 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 [33]. The End-to-End Latency with the number of requests for the users during real-time experimental evaluation is shown in Figure 13, indicating the number of users that are utilized in the system in the presence of high mobility. Likewise, Figure 14 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. Figure 15 shows the network lifetime with the number of Mobile Nodes for two schemes. It is important to notice that the network lifetime is significantly extended by using the proposed one and two level BTD for enabling Energy Conservation.

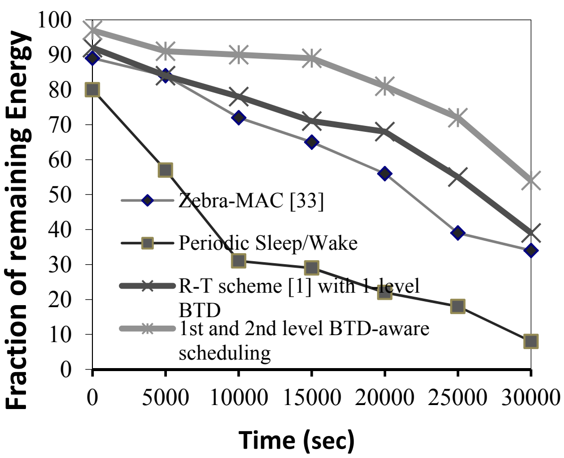

Figure 12. The fraction of the remaining Energy through time using real-time evaluation for different schemes.

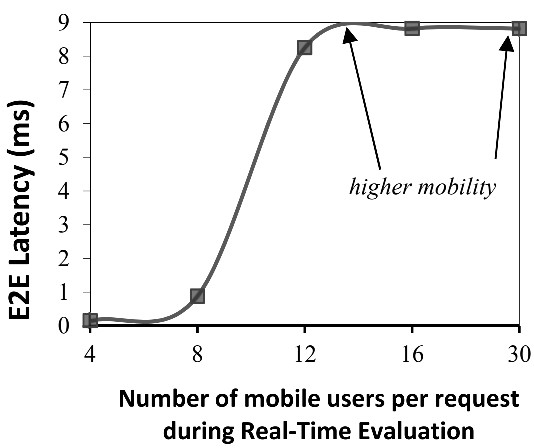

Figure 13. The End-to-End Latency with the number of requests for the users during real-time evaluation.

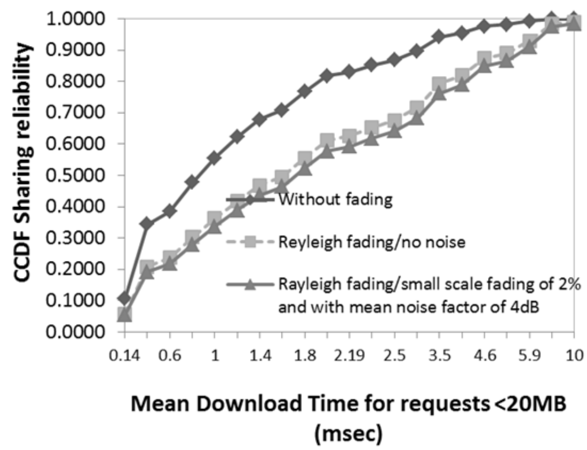

Figure 14. The CCDF for the Sharing Reliability with the Mean download Time for requests over a certain capacity.

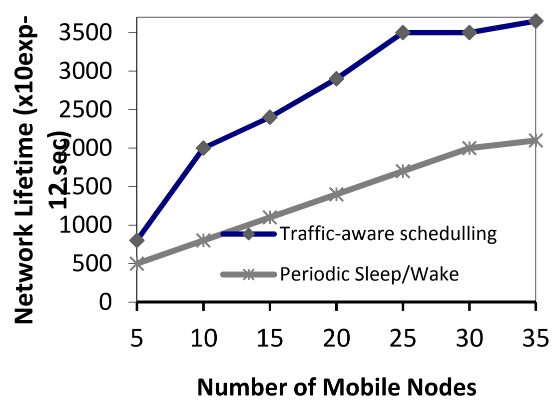

Figure 15. Network Lifetime with the Number of Mobile Nodes.

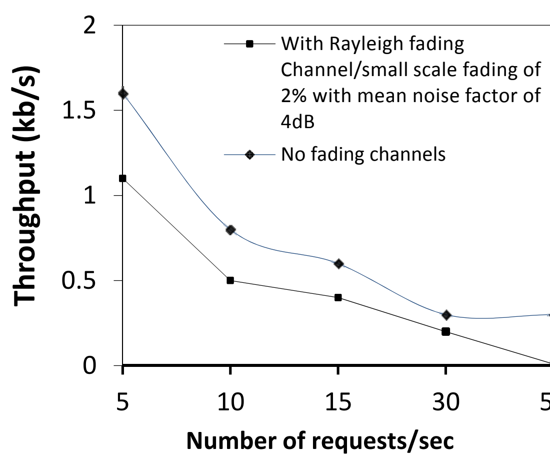

Figure 16. Throughput response of the system hosting the proposed scheme with the Number of requests for certain fading measures' characteristics.

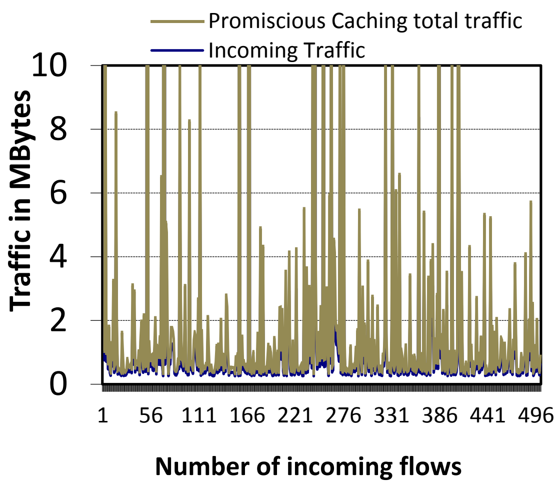

Figure 17. Number of incoming flows on each node in real-time with the incoming traffic in MB, for both the cached traffic and the traffic that a node is expecting to receive.

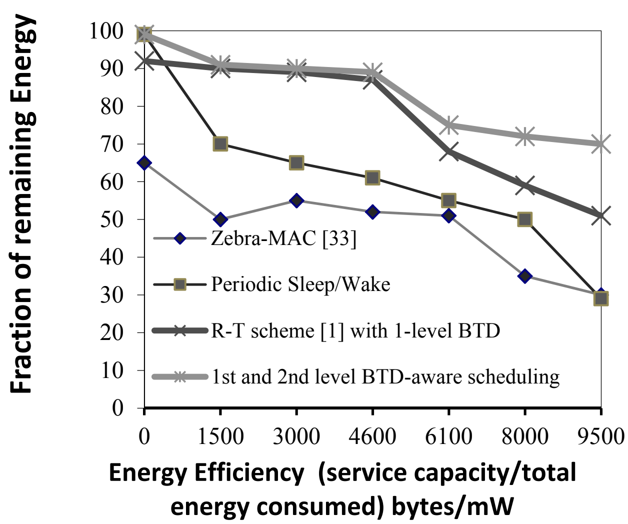

Figure 18. Energy Efficiency (service capacity/total energy consumed) bytes/mW with fraction of the remaining energy onto each node.

The Throughput response of the system under the evaluated two-level BTD in contrast to the number of requests for certain fading measures' characteristics is shown in Figure 16. The proposed scheme shows that in the case of Rayleigh fading characteristics the evaluated Throughput for the two-level BTD in contrast to the number of requests remains at relatively high levels when the number of requests is decreased. Contrarily when the number requests increases the Throughput drops as the Rayleigh fading takes place. This is somehow expected as in the presence of Rayleigh fading the packet transmission and service rate of the wireless channels drops dramatically. In Figure 17, the number of incoming flows on each node in real-time with the incoming traffic, for both the cached traffic and the traffic that a node is expecting to receive is presented. It is important to notice that the cached traffic is not negligible compared with the total volume of traffic that traverses the node. The promiscuous caching enables recoverability of the cached traffic that is forwarded to the destination node. It is obvious that the promiscuous caching enables high SDR rates as data can be recovered, however, it aggravates the energy conservation mechanism by prolonging the next active time duration of the node causing energy consumption.

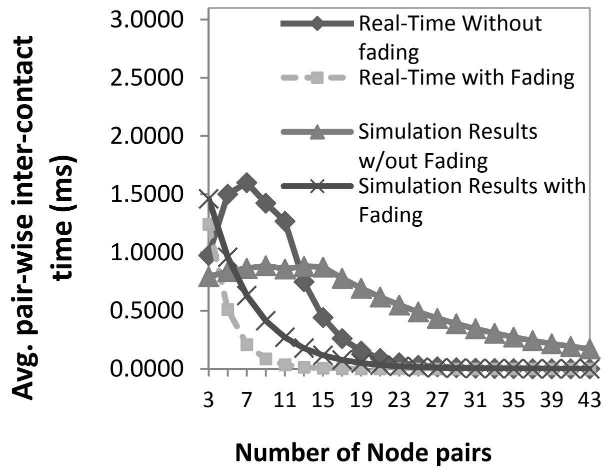

Figure 19. Avg. pair-wise inter-contact time (ms) with the number of pairs that nodes are communicating.

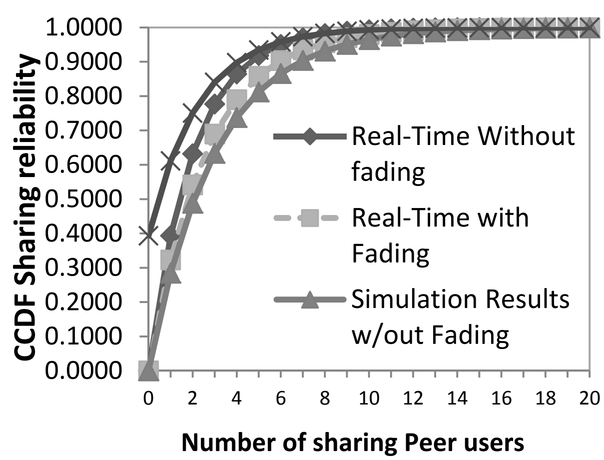

Figure 20. CCDF Sharing Reliability with the Number of sharing Peer-users.

The Energy Efficiency (bytes/mW) which is defined as the service capacity/total energy consumed as in Equation (14), with fraction of the remaining energy onto each node is shown in Figure 18, for 4 different schemes. The proposed framework is shown to have the higher remaining energy for each node in the system whereas, compared to the scheme in [1] it is shown to have an optimized Energy-Efficiency behavior as it allows greater Energy-Efficiency in contrast to the remaining Energy of each node. Scheme adopted by [33] is shown to have the lowest Energy-Efficiency behavior compared also with the periodic sleep-wake schedules.

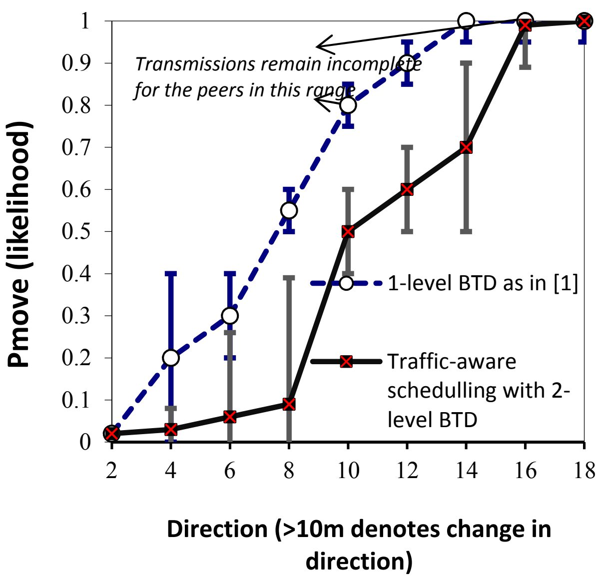

Figure 21. Using the likelihood of Fractional Random Walk (FRW) on a Weighted Graph compared for BTD and two-level BTD schemes.

The main reason that the work in [33] behaves in this way is probably the communication structure of Zerba-MAC which it still relies on time slots similar to TDMA-based solutions. Hence, each slot is tentatively assigned to a node whereas, it can be stolen by other nodes if it is not used by its owner. In Figure 19, the average pair-wise inter-contact time (msec) with the number of pairs of participating nodes (1-hop nodes that are supporting the promiscuous caching process) is presented.

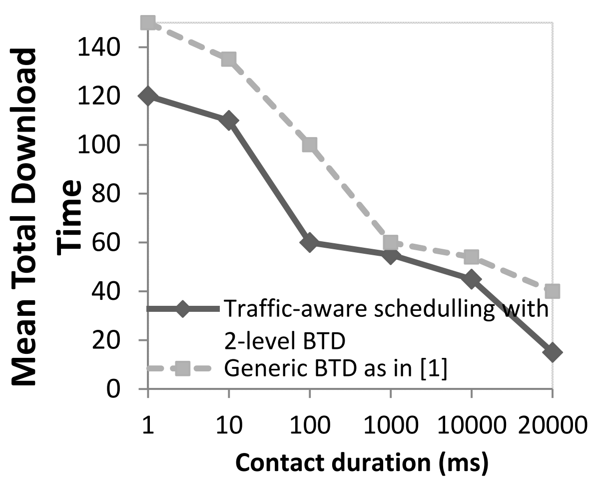

Figure 22. Mean total download time with the peer-contacts and their respective durations.

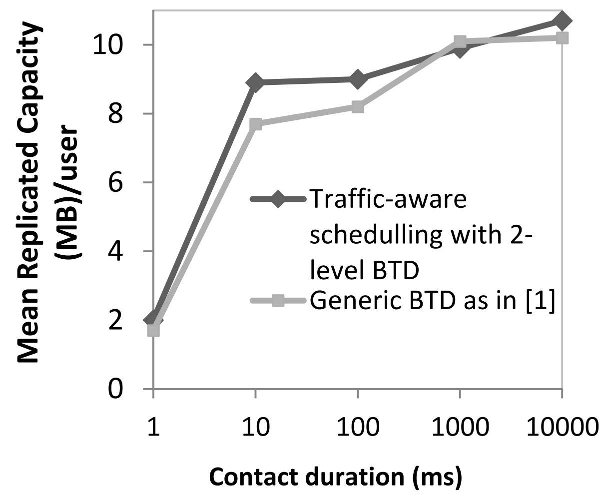

Figure 23. Mean replicated capacity in MB per user with the peer-contacts and their respective durations.

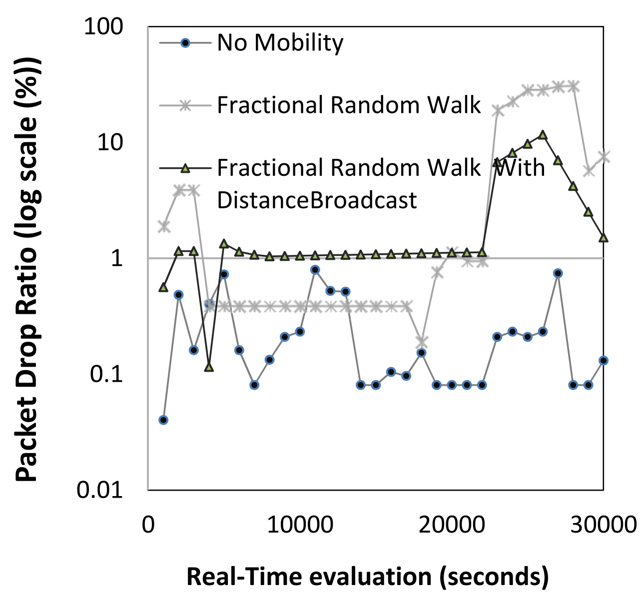

Figure 24. Packet drop ratio during real-time evaluation experimentation for two mobility models and for statically located nodes.

Figure 19 shows that a small number of nodes are directly communicating in the formed cluster within the evaluated area. This inter-contact time is considered very important metric, since participating nodes enable the multi-hop communication for a certain time duration and hence the establishment of End-to-End connectivity. Moreover, the latter enables us to evaluate the performance and robustness of the proposed scheme regarding the support of delay sensitive transmission handling and recoverability effectiveness. Results obtained and presented in Figure 20 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 similar with minor and expected variations (within the confidence interval of 5-7% for the conducted simulation experiments as in [12] and [19]). It can be depicted that the simulated results and the results extracted through real-time traffic and experiments are experiencing 8-12% real values variations.

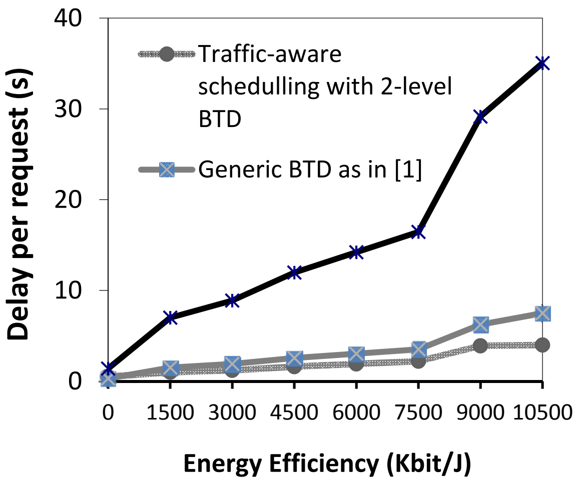

Figure 25. Delay requests in seconds with the Energy Efficiency (Eq. (14)-(15)) compared for three different schemes.

Figure 21 shows the comparison of the two schemes in reference with respect to the likelihood of Fractional Random Walk (FRW) on a Weighted Graph with the average distance for each one of the nodes. The transmissions are interrupted when the transmission distance of the node is increasing whereas, node in reference may find alternative paths to complete the transfers. Figure 22 shows the mean total download time with the contact time for the peers. It is important to mark-out that the proposed optimized scheme in this work outperforms the scheme proposed in [1] allowing less mean total download time and minimizing their respective durations.

The mean replicated capacity in MB per user with the peer-contacts and their respective durations is shown in Figure 23. During the replicated evaluation measures parameters such as the *promiscuous caching* threshold parameter σ_i introduced in [9] were used in order to avoid saturation of nodes [9] and capacity failure due to repeated caching to intermediate nodes. Packet drop ratio during real-time evaluation experimentation for two mobility models is shown in Figure 24. Figure 24 shows that statically located nodes are shown to have the least possible packet drops whereas the proposed scheme behaves satisfactorily when the Fractional Random Walk with Distance broadcast takes place.

The Energy Efficiency is obviously the most important measure for the performance and the energy effectiveness of the proposed scheme. In Figure 25, the delay requests in seconds with the Energy Efficiency (as presented in Equations (14) and (15) compared for three different schemes are shown. It is important to emphasize in the optimization of the Energy Efficiency measures exhibited by the proposed scheme whereas, at the same time to underline the energy differences by the scheme proposed in [1] as well as with the periodic schedules. Figure 25 shows the Energy Efficiency levels in contrast to the delay for each particular request (transfer). It can be depicted that the results extracted for the Energy Efficiency show that the proposed scheme hosting the two-level BTD outperforms the one-level and the periodic sleep, offering in almost all Energy Efficiency levels, minimized delay for the users' requests/transfers.

V. CONCLUSIONS AND FURTHER RESEARCH

This work proposes an adaptive traffic-based mechanism taking into consideration the active moments, and measures the incoming traffic by using the active-time comparisons. Moreover, the proposed two-level backward traffic-difference is presented. This work considers in real-time the one-level BTD scheme and compares the performance with the proposed two-level BTD evaluation hosted on wireless nodes. The proposed methodology takes place during the resource exchange process taking into account the promiscuous caching characteristics and the associated transmission aspects (delay and capacity characteristics) for establishing and maintaining reliable communication. The research framework proposes and provides comparative evaluation of a two-level backward estimation model for allocating the sleep-time duration to a certain node based on the volume of traffic that the node is expecting and admitting (traversed traffic). The proposed scheme aims to further enable Energy Conservation during the resource sharing process of the wireless nodes. The scheme uses the promiscuous caching mechanism for guaranteeing the requested resources and utilizes the one-level and based on delay criteria, the two-level BTD model for the Sleep time estimation. Based on the extracted real-time results and compared to the simulated and results extracted in [1], the designed model guarantees the end-to-end availability of requested resources while it reduces significantly the Energy Consumption. Moreover, the proposed two-level BTD maintains the requested scheduled transfers while, at the same time it increases the throughput response of the system. The evaluated results obtained 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 schemes as well as the one-level BTD scheme in [1].

Next steps and on-going work within the current research context will be the expansion of this model into a variable level-based BTD which will encompass a multi-level Markov Fractality Model (MFM). This fractal model will potentially associate 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 it will maintain a reliable resource sharing process on-the-move.

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