Performance measures of stream-oriented power consumption for asymmetrical communication in wireless ad-hoc networks

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Abstract

Power consumption control in mobile ad-hoc networks is one of the most important issues for enabling a guaranteed Quality of Service in end-to-end transmissions. However recent power consumption control techniques have not yet associated the power control of a wireless device with the content delivery. This means that all transmissions are treated in the same way, which is disastrous in the case of delay sensitive contents in end-to-end connections. In this work the packet stream of a delay sensitive content is modeled and associated with the prioritization of the packets and their spatiotemporal delays. Depending on each stream's characteristics at a certain time, a non-linear communication model is proposed. Adjacent-neighboring nodes with certain transmission power associate their data delay with nodes' capacity measures during data revocation. Following a real time scenario each node has fading characteristics in an entirely asymmetric communication. Performance evaluation results show the efficiency of the proposed model as well as its capabilities under different fading conditions.

1. Introduction

A wireless link has many disadvantages in terms of privacy, vulnerability, and the energy required for data transfer. Recently researchers have focused into views that previously weren't of substantial contribution in the QoS (Quality of Service) maintenance for the end user. On the contrary with wired networks, wireless networks have their own characteristics. The two most important differences between the wired and wireless networks are mobility of the users and location-dependent bit errors of wireless links. These characteristics create significantly different conditions for QoS support.

Ubiquitous computing characteristics of mobile devices (phones and PDAs) equipped with close range radio connectivity like WLAN [1] and Bluetooth [6] create a fertile environment for multimedia applications. These infrastructureless sets of mobile nodes which have no preinstalled components are very flexible and suitable for several situations and applications. Every node acts as an independent router and has limited transmission range, limiting the same time the offered QoS offered to the end users.

An important issue for prolonging wireless network's lifetime, increasing reliability and QoS, is to save power of each network device independently or save power of all network devices of the WLAN [1] in total (WLAN is the most widely adopted standard around the world is IEEE 802.11, 802.15). In many cases the network lifetime could be categorized into different factors that influence performance like the channel metrics knowledge and characterization, fading consequences and approximation techniques [3], as well as real time traffic characterization [4] ect. Some of these parameterized factors could be further examined if particularly merged or combined with other factors as being a part of the problem. In this work a new approach is presented based on the properties of spatiotemporal delay of classified packets. Classified packets [5] have some further characteristics which in some cases (prioritized traffic) these characteristics could be an efficient way for saving power in wireless devices. The proposed approach is based on stream's characteristics as well as relative parameterized factors of the remaining

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capacity of the nearby nodes in a requested path. Progressively the power is saved from node to node, contributing to overall power savings and to significant conservation of the energy. On the positive characteristics of the proposed approach is the usability of the scheme with different routing techniques and delay behaviors. This is also considered as advantageous when compared with other traffic schemes [20], because it accumulates a self tuning scheme for enabling energy conservation using delay measures extracted entirely on stream oriented basis.

The organization of the paper is as follows: Section 2 discusses the related work that has been done on similar energy conservation schemes and the conducted solutions by different schemes. Section 3 then introduces the proposed stream oriented approach based on delay mechanism and characteristics for power saving in wireless ad-hoc environments. Section 4 provides the evaluation of the proposed scheme and presents the simulation results focusing on the behavioral characteristics of the scheme. Finally, Section 5 concludes with a summary of our contribution and suggestions for further research.

2. Related work

A significant amount of research work has already been done in the field of energy conservation both at the routing layer [7-10] and at the MAC and physical layers [11-15]. This work does not involve any layered end-to-end mechanism or enable routing layer involvement. Mainly the proposed mechanism takes action on a MAC and physical layers and the "outcome" is passed to the upper layers of the stack. Quite a lot of protocols have been designed and use different mechanisms to reduce energy consumption; they are classified into two categories: active and passive protocols. Active techniques conserve energy by performing energy conscious operations, such as transmission scheduling using a directional antenna [16], and energy-aware routing [17]. The passive techniques conserve energy by scheduling network interface devices to the sleep mode when a node is not currently taking part in any communication activity (packet forwarding).

Different protocols were designed taking into account many external factors (air, location etc). Some of them deal with MAC layer [7] issues and network layer [17] issues and some are based on topological and geographical information-based techniques (GAF) [18]. Authors in [18] proposed a scheme based on the division of the entire network into small virtual pieces (grids). This area which is recognizable by geographical information, allows only one node to be active in the grid while the other nodes turn off their interfaces to conserve energy. In [19] the goal is to turn off nodes without significantly diminishing the capacity or connectivity of the network. The connectivity and forwarding capability as stated in [19], is maintained by keeping the nodes that constitute a backbone infrastructure, in active mode and switching off the other. Also a traffic-load history determination in association with battery lifetime has been examined in [4]. In [4] the research is focused on load history characterization for each node, targeting the energy conservation for delay and non-delay sensitive services. The self-similarity of packet traffic characterization studied in [4] allows nodes to change their state depending entirely on their traffic history.

A combination of capacity and delay characteristics of an asymmetric wireless communication model is not yet explored in the energy conservation research. While some approaches based on overhearing or fading techniques do not actually address the association of EC problem with any aspects of traffic, in this work this scenario is considered and examined. An attempt in [4] was the cache based determination of the impacts of the EC with the use of dissimilar sleep/wake schedules. This work actually deals with the evaluation and association of packet delay mechanism with nodes' available capacity. Available capacity on each node is a crucial metric for mitigating energy consumption and as discussed in section 3, the association of some metrics with the Stream Oriented Delay Sensitive (SODS) mechanism enables prolonged network lifetime.

3. Stream oriented delay sensitive (SODS) modeling approach based on delay and capacity measures

This section describes the SODS method, which comprises of a mechanism that associates the available capacity of each node, the data rate and the connection characteristics of each device independently[1] with the power saving on each device.

3.1 Scheme's structure and wireless system model

It is of particular interest the examination of EC reduction of each wireless device independently or all

[1] Most researches focus on symmetric devices' characteristics. This work considers an asymmetric model.

of the WLANs' devices in a decentralized form. The affect of the performance while the energy is progressively reduced is studied thoroughly [4, 15-18]. However an association of the capacity measures and metrics with efficient message passing for self-tuning energy consumption is not yet explored. As known the usage of an efficient way in exchanging messages in a distributed decision system plays a major role for the offered QoS parameters. Energy conservation mechanism has to be closely collaborative with the upper layer protocols used, to maintain the packet forwarding mechanism, in an error free mode. An on demand solution must be cost-effective and adaptive, and must be able to keep abreast of any possible changes in the network in terms of load and failures. All these issues must be balanced with the energy consumption or sudden energy deficiency.

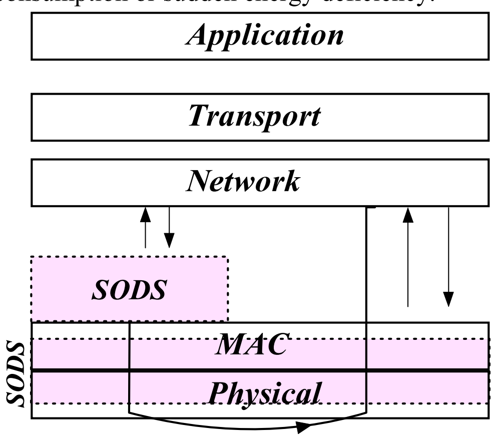

Figure 1: Stream Oriented Delay Sensitive (SODS) mechanism which takes place in Physical and MAC layers of the stack.

It has long been realized that devices' individual communication-related power is usually a significant component of the total power consumed in any wireless network. This work is considering a distance dependant communication. This distance dependant communication can be associated with a particular capacity metric and defines a relation in power-capacity with respect to delay in power saving. The aim of the proposed protocol is to reduce energy consumption by encouraging nodes to "sleep". Before going deeper into power management concepts it is tenable to consider the layered implementation of the proposed scheme. This is shown in Figure 1, where the Stream Oriented Delay Sensitive (SODS) mechanism takes place in Physical and MAC layers. Independently the SODS mechanism runs at each node taking actions for maintenance and urge/instructs the wireless interface hardware to sleep and wake up according to the estimated SODS method. In Figure 1 the SODS entity is presented in shaded form. The SODS entity is the entity responsible for all mechanisms explained in section 3.2.

3.2 Modeling the mechanisms for stream oriented delay sensitive power consumption

According to traffic engineering, the energy that is consumed to transmit a data unit is directly proportional to the total energy consumption by a constant number. Thus if a sender wants to transmit a stream of data at rate R to a receiver, the corresponding transmission power P can be expressed as:

$$P = R \cdot d^r \text{, where } 2 < r < 4 \tag{1}$$

In equation (1), P is the consumed power, r is the path loss exponent based on different channel models, d is the distance between to adjacent wireless nodes, and R is data rate of the channel. Equation (1) assumes symmetrical channels in the communication between devices. In this case according to traffic engineering of symmetric links, power consumption over a long link is much higher than the total power consumption over several short links. Therefore:

$$(d_1 + d_2 + d_3 + ... + d_n)^r >> d_1^r + d_2^r + d_3^r + ... + d_n^r \tag{2}$$

Equation (2) is valid only if we consider symmetric links. Considering asymmetric links between nodes as Figure 2 shows, then the Power consumed equals to:

$$P = \sum_{i=0}^{n} R_i \cdot d_i^r \tag{3}$$

where $R_i \cdot$ is the transmission rate of i link, and d_i^r is the distance of *i-node* to the next node-hop. It stands that:

$$d_1 \neq d_2 \neq d_3 \neq d_4 ... \neq d_n$$

By using an exponential notation, we assume that power is reduced progressively [2, 4] with the remaining capacity on each node, which is evaluated by:

$$P_{i_c} = P_i \cdot e^{e^{C_i}} \tag{4.1}$$

and

$$P_{i_C} = e^{e^{C_i}} \sum_{i=0}^{n} R_i \cdot d_i \tag{4.2}$$

where C is the total data density. Due to fading the power of the radio waves decreases with the distance. Fading is one of the main characteristics of a signal's

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propagation over wireless links. From the aspect of noise and shadowing, fading is not desirable. If we associate the data delay during data revocation from a node with fading characteristics then according to [21], we consider that:

$$\xi_i = \frac{R_i \cdot \Phi_i}{e^{C_j}} \tag{5}$$

where e^{C_j} is storage capacity of the node for which data packets from node *i* are requested.

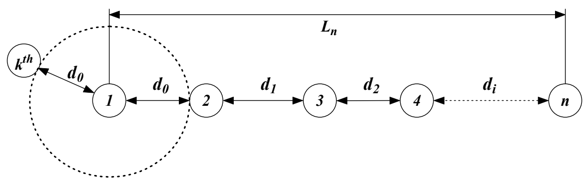

Figure 2: A non-linear communication between adjacent nodes (asymmetric communication).

Thus by encapsulating equation (5), equation (4.2) above can be written:

$$P_i = \sum_{i=0}^{n} R_i \cdot d_i \cdot e^{e^{C_i}}, C_i, \xi_i \geq 0 \tag{6}$$

where equation (6) above estimates the consumed power from node *i* to node *n* over a single asymmetric path. In (6) there is partial association of Energy consumption with capacity and delay characteristics. However these characteristics are not factual since the nature of these characteristics are entirely based on other parameters of the network. An estimation of energy consumption from node i to n is the C_i, ξ_i parameters of i-link/node. Thus our goal is to minimize the P_i, and ξ_i, which is $Min(P_i, \xi_i), Max(R_i)$

To reach the above goal reason we considered a stream oriented approach. As known packets come in streams particularly if these streams are carriers of large data capacity that have file chunk correlations with one another (like multimedia audio and video streams). Time τ is the time required for all of the packets of the stream to arrive correctly at a destination [11, 20].

Let S_n be the streaming packets of a single application. These packets are marked as prioritized. The $S_{t-\tau,j}(S_1, S_2, S_3, ..., S_n)$ is called streaming delay bound, where j is the number of the possible intermediate nodes, that any of the stream packets S_n might follow, and $S_{t-\tau,j}$ is the upper bound of the required time for correct reception of the stream, at the destination. The proposed scenario uses delay sensitive and "don't care" packets [5] (packets that have no time constraints to reach their destination), which need time τ to reach any specified destination. In our scheme "don't care" packets are delayed in intermediate nodes and enforce S_n prioritized packets to continue their journey so that these streaming packets can reach sooner their destination.

The above approach is trying to face in a non symmetric way the problem of delivery of data packets that are prone to variable delays. In a bounded time, these packets must be delivered to the requested destination while delaying the "*don't care packets"* onto intermediate nodes. This delay is estimated by taking measures using the SODS mechanisms explained earlier. However this delay aggravates the remaining capacity of each intermediate node that hosts temporarily data packets. As simulation results show, this aggravation trades off the energy consumed on every node separately, offering an in-time arrival of data packets as well as overall throughput optimization. According to [4, 5] the cached data packets (information) might not be disastrous for the end-to-end delay, if cached packets are manipulated in a specified time interval. By using the SODS method this interval is estimated, pointing out where the range performance of this scheme has bounded values.

This method for energy consumption evaluation bounds many aspects for mobile environments (capacity, delay) and can efficiently host real time multimedia applications by keeping stable the energy consumed. Additionally it provides upper protocol layer independency.

4. Simulation experiments and discussion

The design and evaluation of energy efficient communication protocols requires practical understanding of the energy consumption behavior and understanding of the underlying network interface. To demonstrate the methodology discussed in this paper, we performed exhaustive discrete time simulations of the proposed scenario under several different conditions.

4.1 Specifications and routing protocol used

One basic issue is the selection of the routing protocol that should be used in order to cooperate with the described scenario. 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 [2]. The generated overhead from the route maintenance process, cause

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significant reduction of network performance, increase the end-to-end delays and delay variations [4, 5, 20].

In the implementation of the proposed scenario the Zone Routing Protocol (ZRP) [16] is used. ZRP is a hybrid protocol which combines the reactive and proactive modes. The ZRP is considered advantageous because it allows to a certain node to accurately know its neighbors within a zone. These devices should be in a zone that could be accessible in a fixed number of hops. Since ZRP allow the absolute communication with neighbors, is considered less expensive, while neighbors contribute in the routing process. Particularly, ZRP divides the network into several routing zones which are specified by a determined number of hops. This allows the routing protocol to be adjustable for different operational network conditions such as heavy traffic [13-15].

The specifications used for simulating our scheme are based theoretically on the WaveLAN PC/Card energy consumption characteristics found in the study by Feeney and Nilsson [22]. According to [22] these characteristics can be summarized in Table 1.

Mbps	SLEEP MODE	TRANSMIT	RECEIVE	IDLE
11	10mA	285mA	190mA	156mA

Table 1: Energy consumption characteristics of WaveLAN PC/Card (average current).

Table 1 depicts that the average currents drawn by the card at 4.74 Volts power supply, are measured at 285, 190, 156, and 10 mA for transmit, receive, idle, and sleep modes, respectively. In this way we have approximate reference measures in our simulation scenario, as well as on demand evaluation when transmitting delay sensitive streams, as described in our scenario.

4.2 Simulation results of the proposed scenario

In this section, we present some experimental and simulation results for the performance evaluation and the energy conservation offered by our scheme. The power could be measured by monitoring the three basic metrics-energy components: (i) *transmission* power required to send a packet, (ii) *reception* power required to receive or listen to a packet, and (iii) *idle* power required to stay in at the active state (awake) in contrast with sleep time duration that follows. Transmission power includes both the power required to drive the circuit and the transmission energy from the antenna [1, 2]. Therefore, the energy consumed by any mobile terminal for sending, receiving or discarding a message is given by the linear equation [2] [22] $Energy = m \cdot size + \beta$; where *size* is the message size, m denotes the incremental energy cost associated with the message and β is a fixed cost of each operation.

The energy consumption model used in the simulation, for the calculation of the amount of energy consumed, is based theoretically on the WaveLAN PC/Card energy consumption characteristics found in study by Feeney and Nilsson [22].

In our experiments we took into account newly introduced metrics like $S_{t-\tau,j}$ described earlier which is the upper bound of the required time for correct reception of the stream at the destination, and values of P_i in terms of ξ_i, for $Min(P_i, \xi_i), Max(R_i)$. Some simulation experiments also were performed using different node capacities in order to evaluate the proposed scenario's response in contrast to node's required capacity for maintaining $Min(P_i, \xi_i), Max(R_i)$.

An issue that has to be taken into account is whether the cached information destined for a proper node could be stored in a node with higher residual energy. As simulation process shows, if nodes with higher level of residual energy are chosen in the path, then the network partitioning probability [4, 5] is further reduced. For this reason the cached process which takes place for the "don't care" packets, is chosen on a recursive path basis. This occurs when a source node estimates a certain path and creates at the same time a tree of Node Residual Energy (NRE) in order to enable on demand caching and to assign the certain packets to a certain node.

For implementing the described scenario, we used the spine model of [4] (based on C/Objective C programming language). Topology of a 'grid' based network was modeled according to the grid approach described in [4]. Each node can directly communicate with other nodes if the area situated is in the same (3x3 center) rectangular area of the node. Generally each node can communicate with other nodes if it is set within a block. In the simulation of the proposed scenario we used a two-dimensional network, consisting of 50 dense nodes. The topology changes dynamically as well as density and on a non-periodic basis (asynchronously as real time mobile users do). This issue enables us to examine different connectivity scenarios as well different self tuning abilities of each

[2] Linear regression is used to test the model and find values for m and β.

node. Each link (frequency channel) has max speed of 11Mb per sec (ideal speed), and the propagation path loss is the two-ray model without fading. We have also modeled on each node's communication protocol, an agent for generating and evaluating the data packets that are destined for a proper destination. With agent's contribution we have the ability to take measures and monitor the information destined for each node (for a given time interval) sent by any other node. This is performed by assuming that each node might be the next possible destination at any time. The network traffic is modeled by generating constant bit rate (CBR) flows. Each source node transmits one 512-bytes (~4Kbits) packet. Packets are generated at every time step by following Pareto distribution as depicted in [4], and are destined for a random destination which is uniformly selected.

Figure 3 shows the incoming flow-traffic (in measured packets) at a random node using the Pareto distribution for almost 8,5mins or approximately 500s duration. The generated load by one source is the mean size of a packet train, over mean size of packet train and mean size of inter-train gap or it is the mean size of ON (active) period over mean size of ON(active) and OFF (inactive) periods.

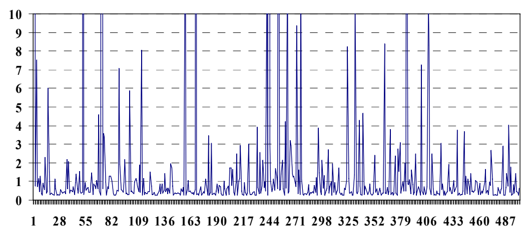

Figure 3: Incoming flow-traffic at a random node using the Pareto distribution for 500 secs ($1 < a < 2$).

Figure 4 shows the number of streams with the ξ-parameter which figures the mean delay during data revocation (μs). When streams are traversing network paths, it is extremely difficult to recall lost or delayed packets. The used SODS method enables fast data recovery even if packets temporarily are cached in an intermediate node. The recall process of the data packets which correspond to certain streams, by using the SODS, seems to minimize further the delays. Figure 4 shows that even if more than >350 streams in the network can be handled with minimum delay of 35-37μsecs.

Figure 5 illustrates the mean power consumed with $S_{t-\tau,j}$ which comprises the upper bound of the required time for correct reception of the stream at the destination node. The mean delay should be minimal for the correct reception of the stream at the destination node. Figure 5 shows that $S_{t-\tau,j}$, is actually bounded in order to enable QoS in an end-to-end communication. It is obvious that for high power consumption values, the mean delay is significantly higher. That is because according to equations (4.2), (5) and (6) the consumed power, from node *i* to node n over a single asymmetric path, will significantly increase the power consumed if the delay sensitive data density is high. This causes the promiscuous caching discussed earlier and in turn the mean power consumed is increased. All the above are aggravated by each node's fading characteristics where, due to fading, the power of the radio waves decreases with the distance and the power consumed is significantly higher.

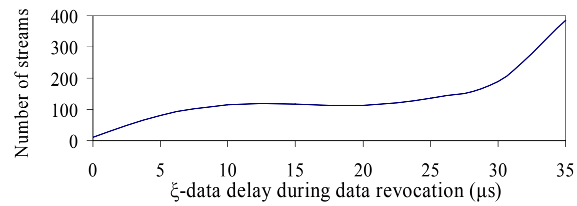

Figure 4: The number of streams with the ξ-parameter (mean delay during data revocation (μs)).

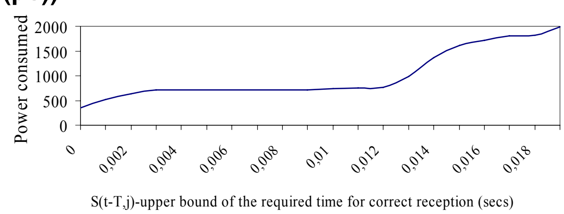

Figure 5: The mean power consumed with the $S_{t-\tau,j}$(upper bound of the required time for correct reception of the stream at the destination node).

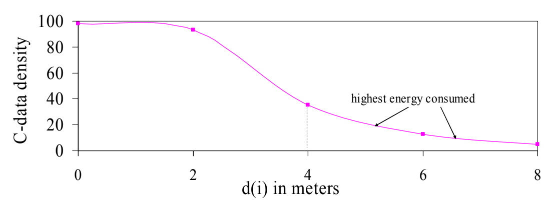

Figure 6: C-data density versus the average distance d(i) of each node in meters.

Figure 6 shows the C-data density (i.e. capacity of a channel) versus the average distance d(i) of each node in meters. C-data density is the percentage parameter showing that when C-data density reaches the 100 then the channels that are traversed are fulfilled in terms of capacity. We compared different distance measures in order to make a distinction of the significant differences for each individual measure. It is remarkable to point out that for >4m the power consumed is significantly above the expected values extracted in [4]. Results in Figure 7 show this principle for 6<d(i)<8.

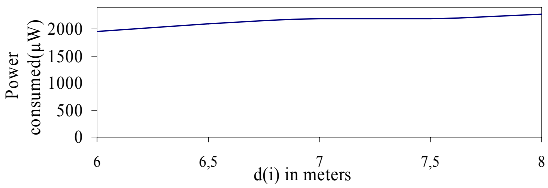

Figure 7: The mean power consumed with the average distance d(i) of each node in meters.

Figure 8 shows the power consumed with the average distance d(i) of each i-node to its subsequent neighbor node-n. It is remarkable to see that remotely hosted neighbors enable more power to be consumed compared with neighbors that are in <7.5 m distance away. Additionally Figure 8 depicts that parameters expressed in equation (6) (about consumed power from node i to node n over a single asymmetric path) for remotely hosted adjacent nodes, can be significant and can cause severe degradation in power conservation.

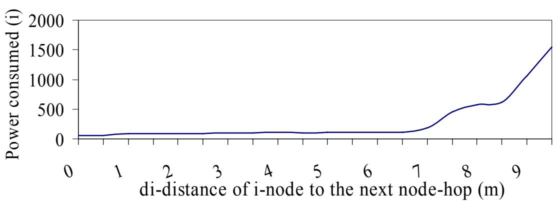

Figure 8: The power consumed with the average distance d(i) of each i-node to its subsequent next node-n.

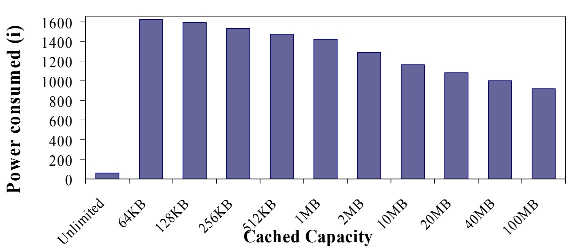

Figure 9: The power consumed with respect to different capacity measures for each node.

Figure 9 shows the power consumed with respect to different capacity measures for each node. Of considerable interest is that the bounded -but higher-capacity (100MB) can conserve energy on each node during the caching process. Along the same lines the unlimited capacity measures can save energy and have the minimal energy consumed.

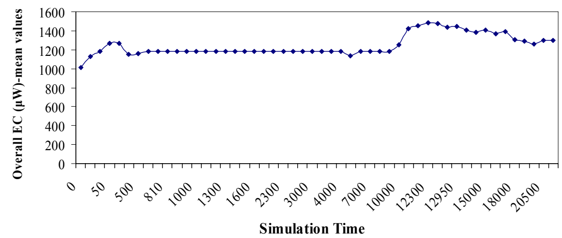

Figure 10: Mean Energy consumption in each network's zone (ZRP-based) at any time during simulation.

Figure 10 illustrates the mean Energy Consumption in each network's zone (using the ZRP) for delay sensitive traffic at any time during simulation. From Figure 10 it can be extracted that the overall energy consumed is as expected compared with the results extracted in [4]. However there are some slopes during simulation time, for which the energy is periodically increased. The most significant outcome of Figure 10, is that the energy consumed remains at relatively low levels even if the data packets contain delay sensitive information. This denotes that the association of the exponential nature (equation 6) of the capacity with node's communication distance and the prioritization of delay sensitive packets can be efficient in modeling an energy conservation mechanism. Thus as results show the P_i is significantly minimized as well as ξ_i for $Min(P_i, \xi_i), Max(R_i)$.

5. Conclusions and further research

In this paper, we have proposed an association of the power consumption control with some crucial metrics for Quality of Service in mobile ad-hoc networks. Transmissions that are delay sensitive are treated as prioritized in end-to-end connections. Therefore in this work we have modeled and associated metrics that characterize packet streams (which contain delay sensitive data) with the prioritization of the packets and their spatiotemporal delays in terms of channel capacity, asymmetric distance among nodes, and data density. A non-linear communication model is proposed where the transmission power of the adjacent nodes, associate the data delay with capacity measures during data revocation. Simulation experiments show that the followed real time scenario is strictly efficient and the associated metrics can handle efficiently an 802.11 environment with the above characteristics and under asymmetric fading conditions.

A lot of research work remains to be done. A further examination of such scenarios with thorough modeling will be the subsequent steps in our research. The exponential nature of crucial metrics (i.e. channel capacity, data packet delays, packet loss, interarrival delay variations) is always an open ended issue particularly in dynamically changing topologies. Also an association of the capacity measurements with different traffic patterns and content efficient delivery would be of great research interest.

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