Buffering Techniques in Sleep Doze Coordination and Grid Based Clustering Protocols as Power Management Schemes for Wireless Sensor Networks

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Abstract- **In this paper, we outline an approach to improve the lifespan of a wireless sensor network by introducing a variant to standard sleep synchronization protocols. A multilayered architecture is used. To ensure even higher scalability and lower message size in any particular layer, number of layers is limited to four and each layer is broken into grids. Each grid acts a localized network where data aggregation and lifetime maximization algorithms are being run. In standard sleep protocols like GAF, each grid must have one of its nodes in active state. Our sleep protocol considers one node per grid to be in the idle listening state called the 'doze' state for a fixed interval of time. Thus we propose a three state proactive algorithm in the form of the Sleep Doze Coordination (SDC) protocol to lower the duty cycle of the each sensor node and maximize the network lifespan with lower power consumption. Node buffers are provided to bring about higher data accuracy and lossless network operation. When node buffer gets filled to its capacity by data messages from the lower layer, it signals the 'dozing' node to transit to the active state. Thus the node does not have to remain active throughout its 'on' period and its overall lifespan increases for a given amount of energy. Results indicate that near-optimal performance of SDC is achieved when buffer size is large enough to hold 25 data messages. SDC increases network lifetime by approximately 20% over previous protocols like GAF and S-DMAC.**

Keywords- **wireless sensor networks, duty cycle, SDC protocol, queueing discipline, M/M/1 queue, buffering.**

I. INTRODUCTION

WIRELESS sensor networks(WSN) are gaining popularity in numerous applications from military surveillance to under water event sensing. WSN can be easily deployed to various environments to monitor target objects and various conditions, and to collect information. Typically WSNs have a large number of sensor nodes that can communicate among themselves and also to an external sink or a base station. Data aggregation is performed periodically to collect the most critical data from the sensors and make them available to the sink[1]. But, it has to preserve enough energy to maximize network lifetime and simultaneously ensure high performance of network(throughput) and a threshold level of data accuracy[1],[2].

This paper focuses primarily on these aspects when sensor network is put to use in low energy, low bandwidth applications (WLAN security). The US Army's Future Combat Systems [8] relies heavily on remote unattended sensors to detect, identify and track enemy targets in order to survive with less armour protection. Deployment occurs in rugged inhospitable terrains. Specific instances of standard remote oil pollution detection systems have four subsystems: optical sensor, wireless telemetry package, power supply and base station. Often agricultural researchers have to scatter a million battery-powered, smart-dust sensors by helicopter to monitor water levels across large cornfields. In the lines of such real-life layered sensor deployment environments, we propose a grid-based WSN (gb-WSN) architecture. Each layer is composed of multiple grids. Data flows from the bottom layer to the top[2](fig. 2). Sleep synchronization algorithms like Geographic Adaptive Fidelity (GAF) [5] and Sensor D-MAC [13] run in the lower layers to allow for a maximum period of sustenance of network connectivity. Our contributions to the previous work are as follows-

i) As opposed to two state protocols (GAF), we excogitate a three state sleep protocol, in the process lowering the duty cycle[12] and making it more cost effective and increasing network lifetime.

ii) In the quest for an optimal buffer size, we have used a power aware buffering (PAB) approach proposed in [3] and we have mathematically shown the variation of duty cycle with the buffer size and energy consumption of the network.

iii) We have used a grid based three layer approach to WSN over any standard layering approach[4] and shown that reduced message size results in lower routing energy cost.

Grid-based routing was considered once previously by Zhang [9] for WSNs where in a single large chess-board type (n×n) sensor area, each small square was taken as a grid. Here, an efficient graph-based routing algorithm were developed to provide shortest-cost paths for grid-to-grid communication. Grids were considered just to construct a path to the base station. Our concept of grid is derived from cellular networks [11]. But in general, a better approximation should be a convex polygon e.g.- hexagon in cellular networks. However, such grids are impractical for implementation purposes in WSN. Thus for simplicity, we adopt Xu's approach [5][13] in developing our routing grids i.e. square grids. Deployment of redundant number of nodes is avoided in most cases, as it is impractical from the perspective of cost incurred. The network for gb-WSN is composed of four distinct layers namely:

i) **Layer C** – This layer has a master-slave architecture (e.g.- piconets in Bluetooth [6]). The bottom layer has two sublayers:-

a) **The lower sublayer (C_{lower})** of comparatively inexpensive sensors like static seismic, acoustic detectors or thermal sensors. In this layer, even nano-sensors such as Carbon nano tubes may

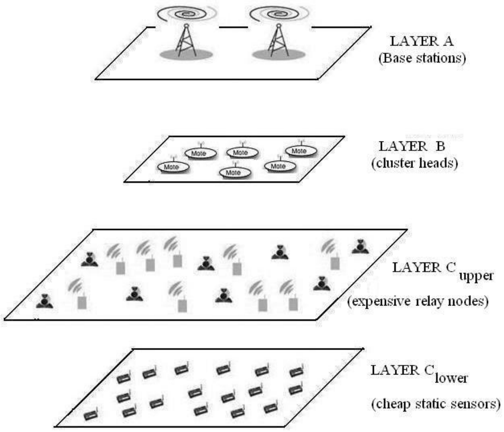

Figure 1 – Layered Architecture of the grid based WSN (gb-WSN)

be used for detection of specific organic and inorganic impurities in ocean water for pollution detection. C_{upper} layer sensors act as cluster heads or sinks to C_{lower} layer sensors. Node deployment should be in redundant numbers to ensure network coverage.

b) **The upper sublayer (C_{upper})** of expensive relay nodes, sensors like visual cameras or recording devices. They are capable of mobility and unlike C_{lower} are provided with buffers (PAB). Also these sensors may possess satellite uplink capacity and GPS devices as in Coastal Radars (CODARs). We will be discussing SDC protocol for this layer in Section III. The optimal size of $\mathbf{C_{upper}}$ layer node buffers is calculated in Section IV.

ii) **Layer B** - the middle layer has the cluster heads that route data from the lower level sensors to the base station. Cluster heads can be dedicated cluster heads or dynamically selected from lower layer sensors.

iii) **Layer A** - the top layer or the base station. We consider this layer to be a black box. It is involved in processing of data aggregated by the network.

The rest of the paper is divided as follows, Section II describes the background and related work for gb-WSN and SDC protocol, Section III describes the network architecture and the SDC protocol, Section IV mathematically establishes the efficiency of grid-based routing and the SDC protocol, Section V provides the graphs and discusses the impact of the results obtained and Section VI concludes the paper.

II. BACKGROUND AND RELATED WORK

A. Sleep Scheduling - In the lower sub layer C_{lower} of Layer C, sensor motes are cheap, hence static. Energy cost may be due to either packet transmission and sensing. Also application specific filtered message routing cannot be achieved as that would require expensive specialized sensors. The sleep synchronization at this layer is performed by the Geographic Adaptive Fidelity protocol[5](GAF-b). In accordance with this protocol, each sensor mote belonging to a grid can be in two states, namely: active(a) and sleep(s). There also exists a third state, the 'discovery' state which is basically a part of the 'active' state when the node finds out the location of its neighbours by discovery messages. The transition of nodes between these three states has been demonstrated in [5]. Error in sleep synchronization between the different neighbours has been addressed in [4].

B. Data Aggregation – The C_{lower} nodes do not communicate among themselves but provision for data dissemination can be performed by application of SPIN[1]. Data is sent from the lower layers to the higher ones. This is done by Low Energy Adaptive Clustering Hierarchy[2](LEACH) with cluster head Updating after each round. In gb-WSN, each square grid in C_{upper} layer acts the cluster. Data aggregation occurs only in 'alert' state of SDC protocol (Section –III). For each round, one of the active nodes in C_{upper} is selected to act as cluster head based on its residual energy and elevated to Layer B. This layer only consists of the cluster heads either i) dedicated or ii) dynamically selected depending on topology control techniques used. In C_{upper}, when each node performs sensing mechanism, and then generates a message that is forwarded to the corresponding cluster head. LEACH uses classic TDMA based approach to ensure collision free, secure data transmission with low duty cycle. CDMA/FDMA is used for intercluster communication.

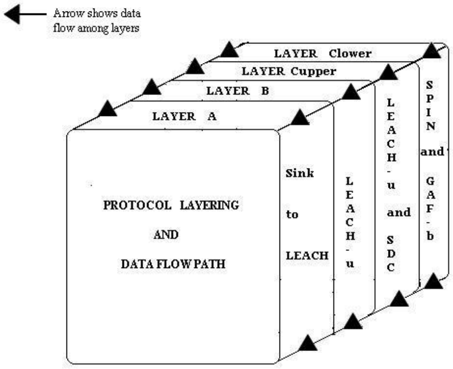

Figure 2 - Protocol Layering and Data Aggregation Path in gb-WSN

III. ARCHITECTURE AND PROTOCOL DESCRIPTION

We consider the whole network to be composed of matrix of grids in seperate layers. This system allows a fine-grain power-management based on actual computational needs. Node in each grid transmits to the immediately higher level nodes which in turn transmits to its sink. The grids are similar to the Geographic Adaptive Fidelity grid (GAF) [5] of C_{lower} layer with grid edge equal to $\frac{\boldsymbol{R}}{\sqrt{\mathbf{5}}}$ [5] where R is the node's sensing range(Fig.3). The grids in C_{upper} act as localized clusters for LEACH.

This distinguishing of grids is important for energy conservation and lifetime maximization of the sensors in Layer C. This grid based routing helps us achieve higher scalability in case of vastly distributed networks i.e. hardware added at the different layers proportional to the capacity increase will guarantee improved performance. Also it has lower data aggregation cost than standard layered networks [6] that will be proved in Section IV. The one-step transition probability matrix for two state sleep protocols (GAF) can be given by:

$P_2(1) = \begin{bmatrix} p_{ss} & p_{sa} \\ p_{as} & p_{aa} \end{bmatrix}$ where p_{ij} is the transition probability from state-i to j in one step, $\sum_{j=1}^{2} p_{ij} = 1\ \forall i$.(s-sleep, a-active, 'discovery' state is actually a part of active state and doesn't contribute to energy efficiency of the network). The upper sublayer C_{upper} is composed of static sensors which only need to be active periodically. However, they being deployed in lesser numbers none of the nodes can be sent to complete sleep mode as that would affect network connectivity. Nodes have more energy and calculating power, and they can also communicate among themselves. Only if lower layer sensors detect threats, 'beacon' message is sent to C_{upper} to activate the appropriate sensors.

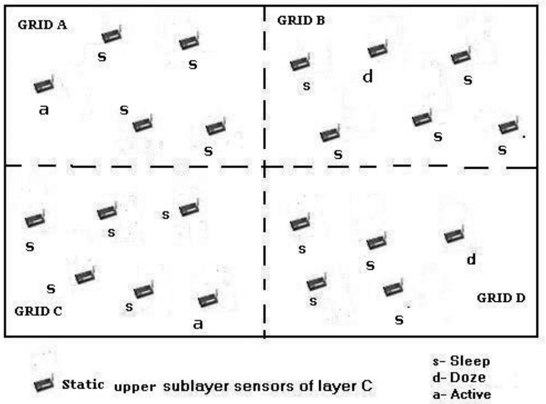

Figure 3 - Subgrids within a single grid for GAF-b in C_{lower}.

Even if tiny Berkeley motes are used, the wireless radio module and the CPU module are the two major energy consumers . In an effort to lower the duty cycle of each node, we postulate that each node has two modes:

(a) "On" period $\begin{cases} \boldsymbol{Alert\ mode(a)} \\ \boldsymbol{Doze\ mode(d)} \end{cases}$

(b) "Off" period or 'Sleep' mode(s)

The corresponding protocol is called sleep-doze coordination protocol (SDC). The topology control method is same as that of GAF. For this three state protocol, the one-step transition probability matrix in Markovian model is given by :-

$$P_3(1) = \begin{bmatrix} p_{ss} & p_{sd} & 0 \\ p_{sd} & p_{dd} & p_{da} \\ 0 & p_{ad} & p_{aa} \end{bmatrix}$$

where $\sum_{j=1}^{3} p_{ij} = 1\ \forall i$;

a) As depicted in Fig.4, 'Doze' state is when the node can receive stimuli from the other sensors- peers or lower level but can't send. In GAF, for each grid, one node was supposed to be in active state. In SDC, a node from each grid is supposed to be in 'doze' state, rest at sleep. Whenever a node switches from sleep state to doze state it sends a 'Hello' message to its peers, who reply if they are active and busy sensing. If the node receives the reply, it immediately becomes active starts sensing. For every node, at the beginning of each round of "on" cycle, the period of staying "on" is set deterministically. Within this period it switches between *doze* and *active* states in concordance with the buffer constraints. The strategy is that, at every instant, at least one of the layer-C_{upper} nodes per grid should be dozing (in contrast, it remains active in case of general 'sleep synchronisation'). Each node is programmed to receive two different types of Beacon messages- a) 'standard' Beacon (size - 128 bytes) and b) 'urgent' Beacon (size-256 bytes).But while it is dozing, if it receives a 'standard' beacon from lower-level sensors (Beacon-I), it buffers them. It services those data when it switches to active state. However, if it receives an 'urgent' beacon (Beacon-II), though in listen mode, the node is able distinguish it because of its larger size. It cannot be stored in a single bank and requires immediate processing and node switches to active mode to service it.

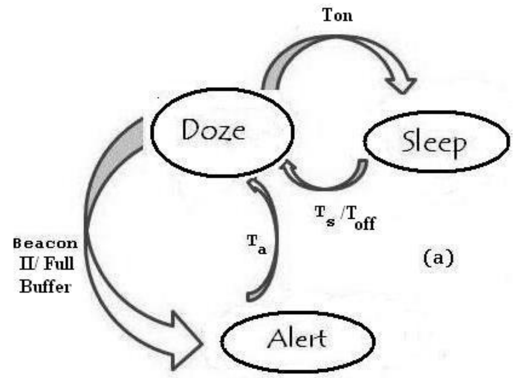

Figure 4 - State Transitions in SDC protocol.

An 'alert' mode sensor can listen for data packets and send them. The 'alert' state has two sub-states- the 'promiscuous' phase and the 'data transfer' phase. During a short 'promiscuous' phase, the sensors immediately on entering 'active' phase, send 'discovery' message to all its neighbours to find out their location and states. The sensors are capable of mobility and can also align themselves in order to achieve best network coverage in this phase. Depending on information from its peers, cluster head calculation takes place. Then the sensor enters a sensing and 'data transfer' phase where sensor senses data and tranmits to the sink. In this phase the nodes are static to allow for feasibility of application of a clustered data aggregation algorithm.

Since the only node in 'on' state is not in complete active state, data that arrived while the node is dozing has to be buffered. Node buffers may be of two types : i) Fixed Size buffer where data is drained out after a fixed buffer size is reached and ii) Fixed Interval buffer where data is drained out after a fixed interval. However, the authors of [3] have shown that approach i) slightly outperforms approach (ii). Hence C_{upper} nodes using SDC adopt a buffer with fixed size.

b) In 'sleep' or 'off' state, the node it is completely inactive and power consumption in sleep state is negligible.

This is a strictly pro-active approach to lifetime maximization as wakeup time is algorithm dependent. So, the doze period of a node is deterministic. This approach is better than a probabilistic one in terms of energy-efficiency (since the node can remain in doze period longer) but it is expensive since it needs a buffer. However the buffer ensures lossless operation of network. But the network may be slow in responding to stimuli from lower level.

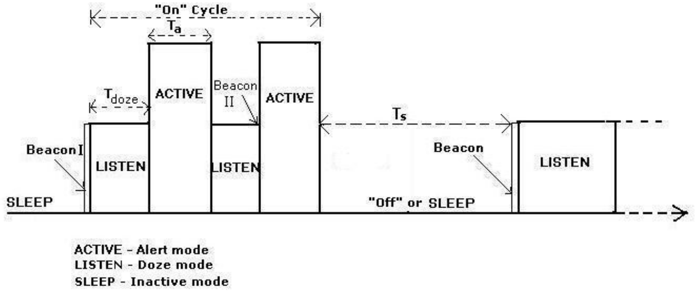

Figure 5 - Sleep Doze Coordination (SDC) in Layer C_{upper} nodes

IV. MATHEMATICAL MODELLING

Sensor node grouping may be of two types:- i) Horizontal(grids) or ii) Vertical(layers). In vertical hierarchy [6], sensor motes are deployed in (say) n layers one above the other as shown in Fig. 6a. The nodes at level *0* send data to nodes at level 1, nodes at level *(i-1)* send data to level *i* and so on. Each node in a higher layer acts as cluster head to a set of nodes in its immediately lower layer. In horizontal hierarchy, nodes are localized in horizontal fashion at the same level in separate grids (Fig 6b). When data aggregation takes place each cluster head gets a compressed message of size $\mu\ (a\times k)$-bit ($\mu \leq 1$ is the compression coefficient) encoded using QAM, where a is the no of lower layer nodes which sends it data. In vertical hierarchy, as data aggregation reaches higher layers, message size increases. For e.g. in layer i, each node receives a message of size $\mu^{i-1}\times(a^{i-1}\times k)$. Energy for transmission(E_i) and message size(k) (Table-I) dependence[10] is shown in the Equation below :

$$E_i = \frac{2}{3} \times NfNoGod^r(2^s - 1)\ln\left(\frac{4(1-2^{-s})}{sPb}\right) \times \frac{k}{s} = E_w^{TX} \times k$$

$$i.e.\quad E_w^{TX}\ \alpha\ k$$

where N_f,,N_o denote noise factors, k is the message size, P_b the bit error probability, s = log M of M-QAM. Thus E_i is directly proportional to message size, so larger the message size, energy cost increases drastically.

Whereas in grid-based horizontal hierarchy, message size reaches a maximum of $\mu^2\times(a^2\times k)$.(μa>>*1* even for the minimum values of μ as a is very large (thousands)) thus making gb-WSN more cost effective than the vertical layering approaches.

In this layer, the modifications to LEACH to ensure complete coverage of the whole sensor networks is called Coverage Preserving LEACH Protocol with Update where threshold for cluster head selection is obtained by [2],

$$T(m) = \begin{cases} p(m)/(1 - p(m) \times (\lambda mod\left(\frac{1}{p(m)}\right)), & m \in G' \\ 0, & otherwise \end{cases}.$$

where p(m) is dependent on the normalized overlapping sensing area. Redundancy required for GAF in C_{lower} is dependent on the inverse of duty cycle.

Death of a node may cause some of its sensing area to become unaccounted for. To prevent this, recomputation of cluster head takes place once after every round of data aggregation.

λ – *Poisson event arrival rate*
μ - *Exponential service rate*
ρ - *traffic intensity*
n - *buffer size (number of memory banks)*
k – *message size*
e_w^{wakeup} - *wakeup energy of radio*
p_m^{idle} - *idle listening power consumption*
e_w^{TX} - *energy for one byte transmission*
e_m^{w} - *energy for reading one byte*
e_m^{w} - *energy for writing one byte*
e_m^{resync} - *total transit energy reqd. for transition from doze to active and then back to doze*
$p^{FS}(n)$ - *power consumption for fixed size buffering*

TABLE – I – Symbols And Meanings

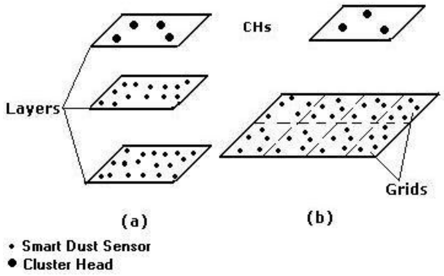

Figure 6 – (a) Vertical Hierarchy (b) Horizontal Hierarchy

We adopt a power-aware buffering approach, we use the fixed size buffering scheme proposed in [3]. Each buffer is composed of *n* memory banks. In this case, when the buffer capacity is reached the node switches from active to doze state.

At any instant of time, the probability that a node will be active is given by its effective duty cycle(ζ)

$$\zeta = \frac{\textbf{node active time}}{\textbf{Ton+Toff}} \;\ldots\ldots\ldots(1)$$

For SDC protocol, a node lifetime is composed of a number of rounds. Each round has an “on” cycle and an “off” cycle. Ton = time period of the “on” cycle and Toff= time period of the “off” cycle or ‘sleep’=Ts.

T_{act},T_s,T_{doze} are the node active, sleep and doze times respectively. Estimated node lifetime(enlt) = Ton+Toff and T_{act}=Ta+Tdoze(as “on” cycle consists of active and doze states). Thus (1) reduces to

$$\zeta = \frac{Ta}{Tdoze+\ Ta+Ts}\ldots\ldots\ldots\ldots\ldots(2)$$

Under the present scheme of buffering(PAB), the buffer will be full and data will be depleted after every n consecutive events. This process is called a renewal reward process where each renewal cycle contains n events. Thus, for the wireless radio module, the energy proposed in [3],

$$e^{FS}(n) = e_w^{wakeup} + p_m^{idle}\sum_{i=1}^{n}(s_n - s_i)$$
$$+n(e_w^{TX}k + e_m^{w}k + e_m^{r}k + 2e_m^{resync})\ldots\text{.(3)}$$

where $s_n \ldots s_i \ldots s_1$ are the arrival times for the respective events i.e.- beacon messages.

Assuming Poisson arrival time, time of one full cycle of filling up of buffer(arrival of n data messages) i.e. $T_{doze} = \frac{n}{\lambda}$, and from renewal reward process,

$$avg\left(p^{FS}(n)\right) \overset{\text{def}}{=} \lim_{t\to\alpha} \frac{e^{FS}(t)}{t} = \frac{avg(E^{FS}(n))}{avg(length\ of\ \text{"on"}\ period)}$$

$$= \frac{E(e^{FS}(n))}{\frac{n}{\lambda}+\frac{n}{\mu}}$$

Substituting the following

$$E\left(\sum_{i=1}^{n}(s_n - s_i)\right) = \sum_{i=1}^{n} E(s_n - s_i) = \frac{\sum_{i=1}^{n}(n-i)}{\lambda} = \frac{n(n-1)}{2\lambda}$$

into Eq^n (3) gives the long run mean power consumption of fixed size buffering as shown below,

$$avg(p^{FS}(n)) = \frac{2e_w^{wakeup} + p_m^{idle} n(n-1)}{2\left(\frac{n}{\lambda}+\frac{n}{\mu}\right)} + \left(\frac{1}{\lambda}+\frac{1}{\mu}\right)^{-1}(e_w^{TX}k + e_m^{w}k + e_m^{r}k + 2e_m^{resync}) \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Minimizing the overall power consumption for an optimal buffer size, solving the Eq^n $\frac{\partial(avg(p^{FS}(n))}{\partial n} = 0$,we get $n_{buf} = \sqrt{\frac{2\lambda e_w^{wakeup}}{p_m^{idle}}}$ ....(5)

For Layer C_{upper} and Layer B, since we have assumed Poisson arrival time (λ) and Exponential service time (μ) of data packets, we apply the *M/M/1* queuing model[14], which is a special case of the *M/G/1* queuing discipline.

Mean service time= 1/μ and mean interarrival time= 1/λ; **ρ = λ/μ**;

From Little's formula[10], we have

queue length = arrival rate(λ) × mean response time(E[R])….(5)

Also, $\mathbf{E[R]} = \lambda^{-1}\frac{\rho}{1-\rho}$ ……………(6)

Since, Little's formula is applicable to a broad variety of queuing systems, and in the present case, we have,

mean queue length = buffer size (n) ……….(7)

combining Eq^n(5),(6) and (7) and eliminating E[R], we get,

$$n = \frac{\lambda}{\mu-\lambda} \ldots\ldots\ldots\ldots(8)$$

In one T_{doze}, *n* data packets arrive and are buffered, $T_{doze} = n/\lambda$

In T_a ,those *n* data packets in the buffer are serviced, $T_a = n/\mu$

Then from (2), duty cycle is reduced to

$$\zeta = \frac{n/\mu}{\frac{n}{\lambda}+\frac{n}{\mu}+Ts} \ldots\ldots\ldots\ldots\ldots(9)$$

Solving putting λ from (4), μ from (8) in (9) we get buffer size (n) in terms of duty cycle (ζ) in the form of

$$\zeta = \frac{1}{2+\frac{1}{n}+Ts\left(\frac{p_m^{idle}(n+1)}{2e_w^{wakeup}}\right)} \ldots\ldots\ldots(10)$$

However to prevent thrashing, enlt ≥ 25sec (a predefined threshold [7]) . So, we take $T_s \geq 30$sec. We assume standard values of the variables in Table –I for e.g. : e_w^{wakeup}, p_m^{idle} are provided in [3] as 0.08mJ and 0.409µW respectively.

Net energy consumption of a sensor node is given by :-

$$E_{total} = E_{radio} \times \zeta + E_{CPU} + E_{buffer}$$

Substituting λ from (5) in Eq^n (3), we get the dependence of energy of the node on buffer size as,

$$e^{FS}(n) = e_w^{wakeup}\left(2-\frac{1}{n}\right) + n\left(e_w^{TX}k + e_m^{w}k + e_m^{r}k + 2e_m^{resync}\right) \ldots\ldots\ldots(11)$$

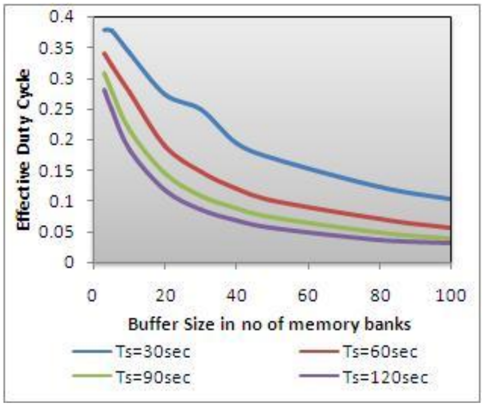

Figure 7 - Effective Duty Cycle vs Buffer size curve for varying Ts

V. RESULTS AND DISCUSSION

We have implemented the network in a simulation environment of VINT project simulator NS2 in Unix environment. For our simulation testbed, we take a network of 10×10 grids each in Layer C_{upper} and C_{lower}. 3 to 7 sensors may be present in each grid. We assume a standard WSN message size(k) of 128 bytes with header. From Eq^n (10), we find as n increases, Ts×n^2 in the denominator increases at a faster rate and duty cycle decreases. From the simulation results, plotting buffer size with duty cycle for various values of Ts in Fig.7 for SDC protocol we find the plot to be in agreement with the buffer size duty cycle relation obtained analytically. In two state sleep protocols (GAF), we had duty cycle ≈ 0.5. We find that three state protocol, SDC shows improved performance with effective duty cycle having a minimum of 0.12 << 0.5 thereby improving network lifetime. The energy-duty cycle relation that emerges from Eq^n (10) and (11) is verified from the simulation results plotted in Fig. 8. We find as we lower the duty cycle of the network, the energy consumption increases due to increased buffer size. Larger buffer requires larger amount of energy for storing beacon from lower level sensors. It contains the simulation graph of the fraction of number of surviving nodes, in general sleep algorithms (GAF here) and that in case of SDC, contrasted. To find a preferable buffer size we assume a value of energy consumption that is tenable in case of low energy low bandwidth sensor networks. It is found to be nearabout 2 mJ. We then come up with a preferable buffer size of approximately 25. Using this preferred buffer size, simulations show that SDC protocol outperforms GAF by about 20% in terms of improving network longevity.

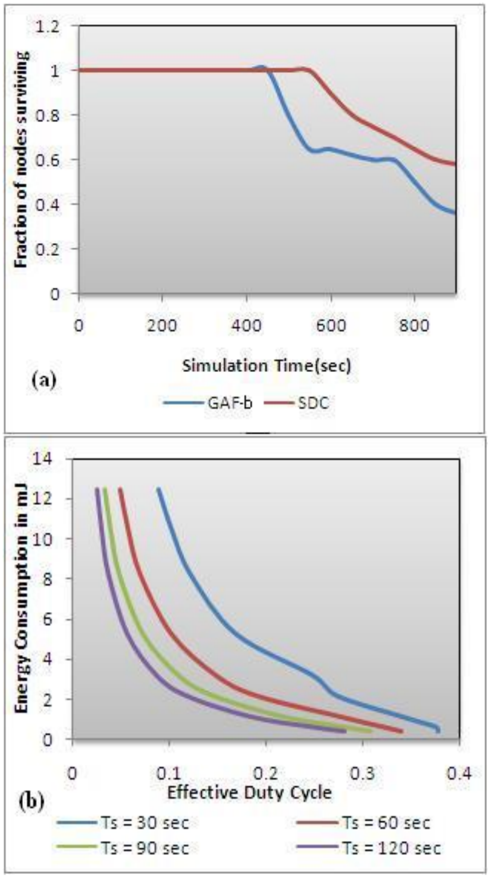

Figure 8 – (a) Contrasting of the fraction of nodes surviving in GAF-b and SDC (b) Energy Consumption vs Effective Duty Cycle curve

The number of nodes exhausted of energy is about 22% more in GAF than SDC as demonstrated in Fig.8. S-DMAC is superior to GAF in the aspects of overall power consumption. Simulations also show that for a node range of $200 \leq n \leq 650$, the decrease in power consumption over S-DMAC for each node increases with greater node density (from 28.6% for n_{min} to 45.8% for n_{max}). This shows that SDC outperforms both GAF and SDMAC at their respective vantage points.

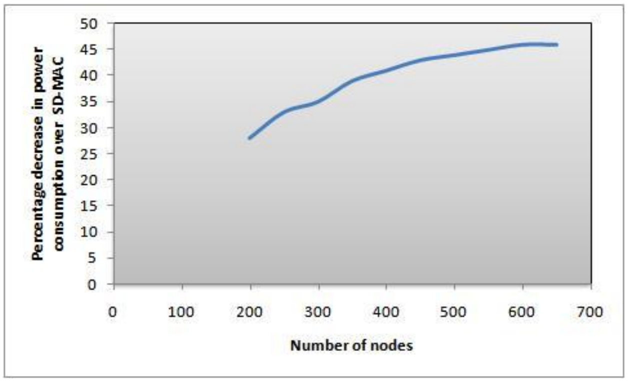

Figure 9- Decrease in power consumption over in GAF over S-DMAC

VI. CONCLUSIONS

This paper introduced the SDC protocol that includes idle listening as a separate state within the standardized sleep protocol for wireless sensor networks. The network uses a topology control algorithm similar to GAF. The introduction of the 'doze' state in SDC successfully reduces the overall power consumption of the network by lowering the duty cycle of the network. SDC has been thoroughly described and relevant mathematical and simulation results have been presented and matched. Both analytical and simulation results show that SDC outperforms previous sleep protocol GAF in terms of the average network lifespan. It also overcomes the limitations of S-DMAC protocol by decrementing the overall power consumption. Network is organized in horizontal grids to lower message transmission cost by reducing message size. Node buffers incorporated reduce the data loss overhead when in idle state. Data messages are buffered in doze state and processed in active state. The time to doze and active time are fixed deterministically due to the fixed size of buffer and this approach is found to decrease the power consumption of the network as a whole.

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