ENERGY EFFICIENT PROTOCOLS FOR SMART DUST

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ABSTRACT

Smart dust is comprised of vast number of ultra-small particles, cubic millimetre in size. These particles together form an autonomous sensing and communication system. We can say that these are extremely small computers in huge quantities working together. Smart dust particles, called "motes," could be as small as the size of a grain of sand. We need that these motes must have long life. To increase the life span of such networks different protocols are there, we study them here.

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I. INTRODUCTION

”Smart Dust” is an emerging technology made up from tiny, wireless sensors or “motes.” Eventually, these devices will be smart enough to talk with other sensors yet small enough to fit on the head of a pin. Each mote is a tiny computer with a power supply, one or more sensors, and a communication system. A year ago, the size of smart dust was about 2 millimetres cubed - smaller than a piece of glitter. An innovation, called Spec, became the first to integrate sensors and transmitters onto a single tiny platform. This opens a platform for a device that senses and communicates on a single chip. Smart dust involves both evolutionary and revolutionary advances in miniaturization, integration, and energy management. **Smart Dust** is capable of gathering many types of information from the environment including temperature, light, humidity and vibrations. It has various application in the field of critical physical infrastructure monitoring, disaster management, monitoring, medical field, military (like forces and equipment monitoring, battlefield surveillance, targeting, nuclear, biological and chemical attack detection), environmental applications (such as fire & flood detection, precision agriculture), and health applications (like tele monitoring of human physiological data).These "smart dust" particles, are able to monitor everything, acting like electronic nerve endings for the planet. Fitted with computing power, sensing equipment, wireless radios and long battery life, the smart dust would make observations and relay mountains of real-time data about people, cities and the natural environment

II. DIFFERENT PROTOCOLS

The protocols for sensor networks we present here are as follows:-

PROBABILISTIC FORWARDING PROTOCOL (PFR)

The author [3] assumes that each grain particle has the following abilities:

i) It can estimate the direction of a received transmission (e.g. via the technology of direction-sensing antennae).

ii) It can estimate the distance from a nearby particle that did the transmission (e.g. via estimation of the attenuation of the received signal).

iii) It knows the direction towards the sink S. This can be implemented during a set-up phase, where the sink broadcasts information about itself to all particles.

iv) All particles have a common co-ordinates system.

Note that *GPS information is not needed* for this protocol. Also, there is no need to know the global structure of the network.

PFR This protocol has the following properties:

- Correctness: It must guarantee that data arrives to the sink S, given that the network is operational.
- Robustness: It must guarantee that data arrives at enough points in a small interval around S, in cases where part of the network has become inoperative.

- Efficiency: It should have a small ratio of the number k of activated particles over the total number N of particles r = kN Thus r is an energy efficiency measure of it.
- probabilistically favours transmissions towards the sink within a thin zone of particles around the line connecting the particle sensing the event E and the sink.

The Forwarding Probability:

Data is propagated with a suitable chosen probability p, while it is not propagated with probability 1 − p. The favour near-optimal transmissions we choose Pfwd =φ/π

The two phases of PFR

Phase 1: The "Front" Creation Phase- Initially we build (by using a limited, in terms of rounds, flooding) a sufficiently large "front" of particles, to guarantee the survivability of the data propagation process. Each particle having received the data, deterministically broadcasts them towards the sink.

Phase 2: The Probabilistic Forwarding Phase: Each particle p receiving info(ϱ), broadcasts it to all its neighbours with probability Pfwd (or it does not propagate any data with probability 1 −Pfwd) defined as follows:

Pfwd = {1 if φ ≥ φ threshold = 134o

{φ/π Otherwise

Result:

It is proved using geometry (i.e. we cover the network area by unit squares and show that there are always particles "close enough" to the optimal line, i.e. with φ > 134o, that deterministically broadcast), that PFR always succeeds in sending the information from E to S when the whole network is operational.

TEEN-THRESHOLD SENSITIVE ENERGY EFFICIENT SENOR NETWORK:

The author in paper [17] discuss the protocol **T**hreshold sensitive **E**nergy **E**fficient sensor **N**etwork protocol (TEEN) is a hierarchical protocol designed to be responsive to sudden changes in the sensed attributes such as temperature. Responsiveness is important for time-critical applications, in which the network operated in a reactive mode. TEEN pursues a hierarchical approach along with the use of a data-centric mechanism. The sensor network architecture is based on a hierarchical grouping where closer nodes form clusters and this process goes on the second level until base station (sink) is reached. After the clusters are formed, the cluster head broadcasts two thresholds to the nodes. These are hard and soft thresholds for sensed attributes. Hard threshold is the minimum possible value of an attribute to trigger a sensor node to switch on its transmitter and transmit to the cluster head. Thus, the hard threshold allows the nodes to transmit only when the sensed attribute is in the range of interest, thus reducing the number of transmissions significantly. Once a node senses a value at or beyond the hard threshold, it transmits data only when the value of that attributes changes by an amount equal to or greater than the soft threshold. As a consequence, soft threshold will further reduce the number of transmissions if there is little or no change in the value of sensed attribute. One can adjust both hard and soft threshold values in order to control the number of packet transmissions.

Problem: TEEN is not good for applications where periodic reports are needed since the user may not get any data at all if the thresholds are not reached. We can list its drawbacks as follows:

a). Hot Spot" Problem

b).Cluster-Heads need to listen constantly

c).Wasted time-slots

d).Can't distinguish dead nodes

e).Other LEACH problems

SLEEP-AWAKE PROBABILISTIC FORWARDING PROTOCOL (SW-PFR):

This protocol avoids flooding by favouring in a probabilistic way certain "close to optimal" data transmissions and also allows particles to alternate between sleeping and awake modes to save energy. The Sleep-Awake Probabilistic Forwarding Protocol (SW-PFR) is designed to effectively reduce redundant transmissions during the dissemination of information in a sensor network and at the same time maintain decent propagation times. The basic idea of the protocol lies in probabilistically favouring transmissions towards the sink within a *thin zone* of particles around the line connecting the particle sensing the event E and the sink. Although data propagation along this line is optimal with respect to energy and time cost, such propagation is not always feasible. This is true because, even if initially this direct line was appropriately occupied by sensors, certain sensors on this line might become inactive, either permanently (because their energy has been exhausted) or temporarily (because these sensors might enter a sleeping mode to save energy). Further reasons include-

(a) *physical damage* of sensors,

(b) *deliberate removal* of some of them (possibly by an adversary in military applications),

(c) *changes* in the position of the sensors due to a variety of reasons (weather conditions, human interaction etc), and

(d) *physical obstacles* blocking communication.

The protocol evolves in two phases like Classic PFR:

Phase 1: The "Front" Creation Phase. Due the probabilistic nature of the protocol there could be many cases of early failures at the propagation towards the sink (i.e. the stochastic process of data propagation may soon die out). Thus, during this initial phase a sufficiently large front is built to ensure that the data propagation process survives for an appropriately large period of time. This front is created by using a "flooding" mechanism for a configurable number of steps. According to this mechanism, the header of each message includes a counter called β. This counter is set to a redefined value by the source particle, when the latter generates the message relative to the sensed event. Following this initialization, each particle, upon receiving a pertinent message containing a positive β counter, reduces its value by 1 and *deterministically* forwards the message towards the sink. In order to do so, each particle uses directed "angle" transmission to broadcast data to all of its neighbours that lie in the direction of the sink. When the beta counter becomes zero, the particle proceeds to the second phase of the SW-PFR protocol. Ultimately, the beta counter determines the length of the first phase of the SW-PFR protocol.

Phase 2: The Probabilistic Forwarding Phase. In this second phase, data propagation is done in a probabilistic manner. Each particle calculates a probability of participation in the propagation process. The closer a particle is to the optimal transmission line, connecting the source node E detecting an event and the sink S, the higher its probability to forward data pertinent to that particular sense event.

The "forwarding probability" Pfwd is chosen to be Pfwd = φ/π, where φ is the angle defined by (a) the line connecting the particle performing the random choice and the sensor that initially sensed the event and (b) the line connecting this node to the sink. Remark that indeed *a bigger angle* φ *suggests a sensor position closer to the direct line between* E *and* S. Clearly, when $\varphi = \pi$, then the sensor lies on this line. Thus, we get that $\varphi 1 > \varphi 2$ implies that for the corresponding particles p1, p2, p1 is closer to the E-S line than p2, thus

$$\text{Pfwd (p1)} = \varphi 1/\pi > \varphi 2/\pi = \text{Pfwd (p2)}$$

Angle φ calculation. Under appropriate (and realistic) modelling assumptions for sensor particles, angle φ can be locally calculated running a simple sub protocol. Such modelling assumptions include:

a) The ability of sensor particles to estimate the direction of a received transmission (e.g. by direction-sensing antennae)

b) To estimate the distance from a nearby particle that did the transmission (e.g. via signal attenuation estimation techniques)

c) To have a common a common coordinates system

d) To know the direction towards the sink (this is possibly done during a set-up phase). Note that we do not need GPS information or global network structure knowledge.

There are two major additions made to that protocol. First, the current version of PFR, SW-PFR, targets sensor-networks with multiple event generations. In particular, at any given time there could be more than one event being propagated towards the sink. In order to avoid repeated transmissions and infinite loops, each particle is provided with a limited "cache memory". In this cache, the particle registers the event IDs for each distinct event it has "heard of". Each event ID's uniqueness is guaranteed, by choosing it to be a concatenation of the source particle ID and the timestamp of the sensed event. Upon the receiver of a message, a particle checks whether the pertinent event is enlisted in its cache. If that event is not in the particle's cache, it is registered and then the particle proceeds to the proper actions defined by the PFR protocol. However, if the event was already seen, the message is dropped and no further action is taken. As a **second modification,** this version of PFR, SW-PFR, encompasses an intriguing sleep-awake scheme. According to this scheme, each particle goes though alternating periods of "sleeping" and "awake". During a sleeping period, the particles cease any communication with the environment, thus the power consumption is assumed to be minimal and practically insignificant, whereas when a article is awake, it consumes the regular amount of energy. In addition, a special energy amount is considered to be spent during the transition from "sleep" to "awake". It is assume that the sleeping/awake time periods alternate stochastically independently in each particle and have durations s & w respectively

The sleep-awake scheme is basically achieved by setting a global ratio, which defines the proportion between the durations of the sleep and awake periods. The timer's expiration marks a switch over to the alternate mode. The duration of T is defined as the sum of the duration of the sleep and awake periods. Therefore, it is ensured that the sleep-awake transitions do not occur simultaneously, but rather in a random manner. Let now γ = sw i.e. γ represents the energy saving specifications of the smart dust particles (a typical value for γ may be 100). Then,

The energy saving specification is: en = s/s+w= 1-1/1+ γ.

THE HIERARCHICAL VERSION OF THE THRESHOLD SENSITIVE ENERGY EFFICIENT NETWORK PROTOCOL (H-TEEN):

In this particles self-organize into clusters and build a tree of transmissions, propagating data only to their parent (cluster-head) in this tree.

In particular, the author extended the concept of clustering used in the original TEEN protocol to that of Hierarchical clustering. In large area networks and when the number of layers in the hierarchy is small, TEEN tends to consume a lot of energy, because of long distance transmissions. On the other hand, when the number of layers increases, the transmissions becomes shorter, however there is a significant overhead in the setup phase as well as the operation of the network. This protocol implements a *4-layer* hierarchical clustering. The main idea behind the hierarchical clustering is to enable the TEEN protocol to operate in networks that occupy large areas and try to overcome the problem occur in TEEN Protocol.

Let n be the number of smart dust particles and let d (usually measured in numbers of particles/m2) be the *density* of particles in the area.

There is a single point in the network area, which we call the sink S, and represents a control centre where data should be propagated to. Furthermore, it is assume that there is a set-up phase of the smart dust network, during which the smart cloud is dropped in the terrain of interest, when using special control messages (which are very short, cheap and transmitted only once) each smart dust particle is provided with the direction of S. By assuming that each smart-dust particle has individually *a sense of direction*, and using these control messages, each particle is aware of the general location of S.

Each particle may have two communication modes:

a). A ***broadcast* (digital radio) *beacon mode*** which can be also a directed transmission of angle α around a certain line

b). A ***directed to a point*** data transmission mode (usually via a laser beam).

Both the transmission range (which we denote by R) and the transmission angle (let it be α) can vary. The protocols we study in this work can operate even under the broadcast communication mode. The laser possibility is added for reducing energy dissipation in long distance transmissions. Each particle can be in one of four different modes at any given time, regarding the energy consumption.

These modes are: (a) transmission of a message, (b) reception of a message, (c) sensing of events and (d) sleeping. During the sleeping mode, particle ceases any communication with the environment, thus it is unable to receive any message or sense an event. In our model, we assume that the energy consumption of a sleeping particle is negligible, but it needs a certain amount of energy to return to the sensing state.

Following [9], for the case of transmitting and receiving a message we assume the following simple model where the radio dissipates Eelec to run the transmitter and receiver circuitry and ϱ amp for the transmit amplifier to achieve acceptable SNR (signal to noise ratio). It also assumes r2 energy consumption due to channel transmission at distance r. Thus to transmit a k-bit message at distance r in our model, the radio expends

$ET(k, r) = ET{-}elec(k) + ET{-}amp(k, r)$

$ET(k, r) = Eelec \cdot k + \varrho\, amp \cdot k \cdot r2$

and to receive this message, the radio expends

$ER(k) = ER{-}elec(k)$

$ER(k, r) = Eelec \cdot k$

where ET−elec, ER−elec stand for the energy consumed by the transmitter's and receiver's electronics, respectively.

Concluding, there are four different kinds of energy dissipation which are:

- ET : Energy dissipation for transmission.
- ER: Energy dissipation for receiving.
- Eidle: Energy dissipation for idle state.
- Epowerup: Energy dissipation for returning from sleeping state.

For the idle state, it is assume that the energy consumed for the circuitry is constant for each time unit and equals Eelec (the time unit is 1 second). On the other hand, the power up energy equals three times the amount of energy consumed in a time unit during the idle state, that is 3 · Eelec.

The particles in the H-TEEN protocol do not exploit the ability to get to sleeping mode, thus in that case the energy dissipation is characterized by the rest three types of energy consumption.

Finally, we assume that each particle, in protocol H-TEEN, does not spend any amount of energy to listen what the other nodes, of its cluster, send to the cluster head.

But this model is weaker in the sense that *no geo-location abilities* are assumed (e.g. a GPS device) for the smart dust particles leading to more generic and thus stronger results.

Problem:

a) ***Generalization*** of the single event propagation problem, which is more difficult to cope with because of the severe energy restrictions of the particles.

b) Multiple event propagation problem

SENSOR PROTOCOLS FOR INFORMATION VIA NEGOTIATION:

SPIN focus on the efficient dissemination of individual sensor observations to all the sensors in a network. However, in contrast to classic flooding, in SPIN sensors negotiate with each other about the data they possess using meta-data names. These negotiations ensure that nodes only transmit data when necessary, reducing the energy consumption for useless Transmissions. SPIN is among the early work to pursue a *data-centric* routing mechanism. The idea behind SPIN is to name the data using high level descriptors or meta-data. Before transmission, meta-data are exchanged among sensors via a data advertisement mechanism, which is the key feature of SPIN. Each node upon receiving new data, advertises it to its neighbour's and interested neighbours, i.e. those who do not have the data, retrieve the data by sending a request message. SPIN's meta-data negotiation solves the classic problems of flooding such as redundant information passing, overlapping of sensing areas and resource blindness thus, achieving a lot of energy efficiency. There is no standard meta-data format and it is assumed to be application specific, e.g. using an application level framing. There are three messages defined in SPIN to exchange data between nodes. These are:

1). ADV message to allow a sensor to advertise a particular meta-data,

2). REQ message to request the specific data

3). DATA message that carry the actual data

One of the advantages of SPIN is that topological changes are localized since each node needs to know only its single-hop neighbours. SPIN gives a factor of 3.5 less than flooding in terms of energy dissipation and meta-data negotiation almost halves the redundant data.

However, SPIN's data advertisement mechanism cannot guarantee the delivery of data. For Instance, if the nodes that are interested in the data are far away from the source node and the nodes between source and destination are not interested in that data, such data will not be delivered to the destination at all. Therefore, SPIN is not a good choice for applications such as intrusion detection, which require reliable delivery of data packets over regular intervals.

Problem: The main drawbacks of this protocol are:

a) Broadcast - Limited Scale – every node handles O(n) messages

b) Data is updated throughout network – unnecessary in many cases

c) Network lifetime - not clear

d). High degree nodes = High power need.

III. CONCLUSION

Each of protocol has its own specifications and good in different conditions. Like S- PFR and SPIN are having their best efficiency in different schedule for sleeping and awaking periods of node. PFR manages to propagate the crucial data across lines parallel to ES, and of constant distance, with fixed nonzero probability. It also works quite well for all network sizes and injection rates and tends to strain the particles which lie close to the sink more. SW-PFR seems more robust in the case of high rates of event generation and large networks. H-TEEN behaves very well on small network size and low injection rate settings, while it is "expensive" on large network areas and high injection rate and seems to perform better in smaller networks. SPIN is good where topological changes are localized and for data centric mechanisms.

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