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DISTRIBUTED POWER CONTROL WITH ENERGY EFFICIENT FORWARDING ROUTING PROTOCOL FOR WIRELESS SENSOR NETWORK

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Abstract: In wireless sensor network, to prolong the lifetime of the Sensor network, low power consumption is needed which can be obtained by facilitating low duty cycle and local signal processing. Thus a power control mechanism has to be designed and used to minimize the energy consumption. In addition to this, an energy efficient MAC and routing protocol is needed to reduce energy cost of sensor nodes. To establish an effective transmission power control mechanism, the dynamics between Link Quality indicator (LQI) and Received Signal Strength Indicator (RSSI) values are studied. In the energy efficient forwarding scheme, the data forwarding probability is adaptively adjusted based on the measured loss conditions at the sink In order to minimize energy consumption, we developed a Distributed Power Control with Energy Efficient Forwarding Routing Protocol (DPC-EEFRP) using E3-MAC Algorithm which enables all nodes on the path to stay active and/or increase their duty cycles and all other nearby nodes to sleep in order to enable continuous data forwarding without incurring energy waste of unrelated nodes.

Keywords: Sensor Networks, DPC-EEFRP, Power Control, Average Energy.

1. INTRODUCTION

Sensor networks [1] – networks of tiny nodes equipped with limited sensing, computing, and radio communication capabilities – is a technological vision that is currently receiving a lot of attention from several research communities. Such sensor networks would use wireless communication to transmit their observation values to a given monitor station which would serve as a user interface.

Low-power, cheap and minute distributed devices are widely used in the real time local processing and wireless communication with the advancement of technology. Usually in a sensor network, sensor nodes are connected to a central processing station. Recently, the focus is upon the wireless, distributed sensing nodes. In fact, closer allocation is permitted by the distributed sensor but only after the knowledge of the correct location specified, the allocation is permitted in a single sensor. Environmental obstacles like line of sight constraints can be overcome by the multiple sensor nodes. The environment considered here doesn't possess an infrastructure for energy or communication. The sensor nodes need to endure on minute, finite energy sources and wireless communication compulsorily. [3]

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Sensor networks are useful in many areas in various ways. For example, environmental monitoring is done which includes examining air, soil and water, condition based maintenance, habitat monitoring (estimating the population and behavior of plant and animal species), military surveillance, seismic detection, inventory tracking, smart spaces etc. The pervasive nature of micro-sensors enables the sensor network to realize and assemble complex physical system. [2]

Routing in Sensor networks is very challenging because several characteristics which are different from the modern communication and wireless ad-hoc Networks [ ] and so routing is a difficult task here.

- Construction of a global addressing scheme for the employment of pure number of sensor nodes is impossible. So, sensor networks can't employ classical IP-based protocols.
- The sensor network applications demands the sensed data flow from multiple regions to a specific sink which are entirely different from the characteristic communication networks.
- Due to the generation of similar data within the adjacent area of a phenomenon, redundancies are caused in the data traffic which in turn enhances energy and bandwidth exploitation.
- Sensor nodes demand cautious resource management since they are enclosed in terms of transmission power, processing capacity, on-board energy, and storage.

- In several sensor networks, node failures and packet losses are expected. Due to the temporary wireless interference, these losses are short-term in nature. [3]

In this paper, we propose to develop a Distributed Power Control Energy Efficient Reliable Protocol (DPC-EERRP) with the aim to minimize energy consumption while achieving high reliability in order to ensure high overall network connectivity by using power control Energy Efficient Forwarding and E3-MAC Algorithms.

The reminder of this paper is organized as follows. In Section 2, we introduce previous work related to our study. Section 3 gives description of adaptive power control, Description of DPC-EEFRP protocol in section 4. Section 5 gives simulation results; in Section 6 paper is concluded.

2. RELATED WORK

R. Maheswar, and Dr. R. Jayaparvathy [5] have proposed a new scheme to reduce the power consumption of nodes by reducing the number of transitions of the sensor node based on the number of packets in the queue i.e., queue threshold. They developed an analytical model of a wireless sensor network with finite buffer capacity and analyze the performance of the proposed scheme in terms of performance parameters such as power consumption and mean delay. The design of energy efficient routing algorithm for an HSN will be their future research.

Junseok Kim, Sookhyeon Chang, and Younggo Kwon [6] have proposed an efficient transmission power control algorithm for wireless sensor networks, namely, the on-demand transmission power control (ODTPC) algorithm. This new algorithm attempts to reduce the initialization overhead in determining the optimal transmission power level while providing good link qualities. They also presented a combination scheme of AODV and ODTPC, and the testbed experiment results confirm that ODTPC works well with AODV routing protocol.

Jang-Ping Sheu, Kun-Ying Hsieh and Yao-Kun Cheng [7] have proposed a distributed transmission power control algorithm which enhances the performance of packet delivery ratio. Before designing the algorithm, they firstly investigated the impact of link quality when utilizing different transmission power by analyzing lots of experimental data, and then algorithm is designed based on those experimental results. Here, each node utilizes the RSSI (Received Signal Strength Indicator) value and LQI (Link Quality Indicator) value of the radio to determine the appropriate transmission power for its neighbors.

Manoussos Athanassoulis, Ioannis Alagiannis and Stathes Hadjiefthymiades [8] have described a multi-criteria architecture in order to achieve energy-aware and consistent message forwarding over a WSN. Using the proposed architecture a directed acyclic graph (DAG) is formed throughout the WSN. Such DAG is used for multi-source data aggregation to a single sink. Intermediate nodes evaluate their energy reserve and induced error and decide whether message retransmission is needed.

Xinhua Liu, Fangmin Li and Hailan Kuang [9] have presented a distributed topology algorithm with transmission power adjustment based on optimal number of neighbors to raise the network energy-efficiency and the network throughput by reducing channel competition intensity and simplifying the complexity of initial network topology. In the algorithm, every node can adjust its transmission power level and calculate its optimal transmission power according to the optimal number of neighbors, and a virtual clustering scheme based on optimal transmission power is proposed for network topology control, where the network connectivity is also guaranteed.

El-Hoiydi, J.D. Decotignie and J. Hernandez [10] have proposed Wise-MAC and PTIP for the downlink of infrastructure wireless sensor networks. A comparison was made with PSM, the power save protocol used in the IEEE 802.11 and IEEE 802.15.4 Zig- Bee standards. Analytical expressions were given to compute the power and delay of each protocol, as a function of the wakeup period. It was shown that Wise-MAC provides, for the same delay, significantly lower power consumption than PSM. When the wake-up period can be chosen to be very large, it was seen that all protocols approach the power consumption in DOZE state. In such a case, the PTIP protocol becomes attractive as well, because of its implementation simplicity.

B. Zurita Ares, P.G. Park, C. Fischione, A. Speranzon, K.H. Johansson [11] have investigated strategies for radio power control for wireless sensor networks that guarantee a desired packet error probability. Efficient power control algorithms are of major concern for these networks, not only because the power consumption can be significantly decreased but also because the interference can be reduced, allowing for higher throughput. An analytical model of the Received Signal Strength Indicator (RSSI), which is link quality metric, was proposed.

In our previous paper [12], we developed an Adaptive Energy Efficient Reliable Routing Protocol (AEERRP) with the aim of keeping the energy consumption low while achieving high reliability in order to ensure high overall network connectivity. In that work, the data forwarding probability is adaptively adjusted, based on the measured loss conditions at the sink. So only for high loss rates, a node makes use of high transmission power to arrive at the sink. Whenever the loss rate is low, it adaptively lessens the transmission power.

But our previous approach has certain issues on controlling power.

- The long data periods badly affects the performance of dynamic power control. Efficiency is reduced when there are too long time scales and causes high feedback signaling overhead when the data period has too short time scale.
- The power control loop saves power by following the channel variations closely when the data is sent frequently. Efficiency of Power control is reduced as data period increases which consumes more power [3].
- For replacing or recharging batteries in a WSN nodes energy is not sufficient. For lengthening the network lifetime, energy efficiency is a major issue. Computation devours less energy than communication.
- Energy gets wasted when nodes neither participate in data delivery nor gets into sleep mode.
- Nodes which are not on the path of communication also overhear the communication and waste energy.
- Sensor nodes have limited power supply compared to ad-hoc networks and due to large number of nodes and the environment in which they are installed, recharging of power is difficult. [3].

In order to overcome the power control issues, we proposed to design suitable mechanisms to minimize the loss ratio and to reduce power consumption. For minimizing the loss ratio, nodes with high residual energy and buffer size are selected.

3. ADAPTIVE POWER CONTROL

3.1 Link Quality Indicator and RSSI

The dynamics of the link qualities Received Signal Strength Indicator (RSSI) value and Link Quality Indicator RSSI and LQI values are considered to establish an effective transmission power control mechanism [7]. For transmission power control, we use the RSSI and LQI as binary link quality metrics. Link quality between a pair of nodes is a noticeable function of transmission power. The radio channel communication between a pair of nodes is referred as Wireless link quality.

This technique modifies the function over time, for the estimation of distribution of RSSIs at different transmission power levels and to adapt to environmental changes. From broadcasting a group of signals at different transmission power levels, the function is derived from sample pairs of the transmission power levels and RSSIs. Node's neighbor records and returns the values of the RSSI of each signal that they hear. The proper transmission power levels for neighbors of this node are listed in a neighbor table of each node.

3.2 Power Control Algorithm

The power control algorithm is described below:

1. Let $P = \{P1, P2\ldots\ldots P_n\}$ be the matrix for a given node with different transmission power levels to send signals to their neighbors.
2. Based on the signals sent, each neighbor Ni measures the RSSI values Ri, given by

$$Ri = \{rs_i^1, rs_i^2, rs_i^3, \ldots rs_i^n\}$$

Hence the matrix $R = (R1, R2, \ldots. Rn)$ for each neighbor $N1, N2, \ldots. Nn$.

3. So the relation between transmission power P and RSSI rs is given by

$$rs(Pj) = a_i \,.\, Pj + bi \quad (1)$$

Based on the vectors of samples, the coefficients a_i and b_i of (1) are determined through the least square approximation method.

4. When a node $N1$ sends a packet to its neighbors, it adjusts its transmission power to the level as per (1) and transmits the packet.
5. On receiving this packet, the neighbor measures the link quality (LQ).
6. Then the link quality difference LQD is given by,

$$LQD = ELQ - MLQ$$

Where ELQ is the Expected link quality and MLQ is the measured link quality.

7. If $LQD > LQ_l$ and $LQD < LQ_u$ Where LQ_l is the link quality lower threshold and LQ_u is the link quality upper threshold, then

Node A does not adjusts transmission power.

Else

Notification packet with LQD, is sent to the node $N1$

Node $N1$ calculates a new transmission power level $P1$ for its neighbor

End if

3.3 Energy Efficient Forwarding Algorithm

In our previous work for energy efficient forwarding we propose a protocol in which each node N maintains a Neighbor Information Table (NIT), which contain the fields Node Id, Distance and Cost. Node Id is the id of the neighbor node, Distance is the distance between that node with N and Cost is the power required to send a packet from that node to the sink. CFN- forward node count

Steps involved in the adaptive energy efficient forwarding phase.

- Suppose *N* wants to send the collected data to the sink, it attaches its cost to the data packet and broadcast the packet to the nearest neighbors.
- When a neighbor *N*1 receives the packet from *N*, it first checks its cost is less than that of *N*. If it is less, it further forwards the packet. Otherwise it drops the packet, since *N*1 is not towards the direction of the sink.
- When the packet reaches the destination *D*, it measures the loss ratio (LR), which is the ratio of number of packets dropped and total packets broadcast from the source.
- Then *D* sends this *LR* value as a feed back to the source *N*.
- When *N* receives this value, it checks the value of *LR*. It then modifies the value of *CFN* as $CFN = CFN + \gamma$, if $LR > LR\text{max}$.

Where γ is the minimum increment of decrement count and *LR*max is the maximum threshold value of loss rate.

- It then rebroadcast the data packets with the incremented CFN, so that increasing the reach ability of the sink. The total power required to reach the sink is thus calculated based on the cost field of all the nodes in CFN. For example, if CFN = 4, then the minimum required power will be 4 * cost of each neighbor node in the NIT.
- When the rebroadcast packets reach the destination *D*, it again calculates the losses ratio LR and sends back to *N*.
- It then reassigns the value of CFN, depending on the value of *LR*. Once $LR < LR\text{max}$, then

  $CFN = CFN - \gamma$, until $CFN >= CFN\text{min}$ [11]

4. DESIGN OF DPC-EERFP

DPC-EEFRP is designed with three main goals.

- Providing a simple transmission and low power consumption, power control algorithm and can be easily implemented with routing protocols.
- To minimize the loss ratio and to reduce power consumption.
- To enable continuous data forwarding without incurring energy waste of unrelated nodes.

Low power consumption in sensor networks is needed to enable long operating lifetime by facilitating low duty cycle operation, local signal processing. To prolong the lifetime of the network, a power control protocol can be designed. Here initial phase is taken to find the proper initial transmission power for each neighboring node as soon as possible. The maintaining phase is taken to dynamically determine and adjust the proper transmission power level with environmental change. Power consumption of idle nodes can be reduced by designing an adaptive power control mechanism. An energy efficient MAC is thus needed to reduce energy cost of sensor nodes. We need a MAC that can tell all nodes on the path to stay active and/or increase their duty cycles and all other nearby nodes to sleep in order to enable continuous data forwarding without incurring energy waste of unrelated nodes.

4.1 Enhanced Energy Efficient MAC (E3-MAC) Algorithm

In order to minimize energy consumption, the proposed E3-MAC makes two important modifications over the existing S-MAC protocol [13]:

- By having all nodes turn off their radios much earlier when no data packet transfer is expected to occur in the networks.
- By eliminating communication of a separate RTS control packet even when data traffic is likely to occur.

S-MAC has the long listen interval, divided into three parts for SYNC, RTS, and CTS packets, respectively.

The steps involved in the E3-MAC are as follows:

1. E3-MAC divides listening interval into two periods WithDATA and WithoutDATA.
2. In WithoutDATA period.

   Node will delay a time for sending its own SYNC into the second part of the listen interval.

   When SYNC is received by a node, it is allowed to sleep.
3. In WithDATA period,

   3.1 The node combines RTS to the SYNC which is called the SYNCrts and transmits it to the second part of listen interval.

   3.2 When nodes receive SYNCrts packet by the end of WithDATA time interval, information about the receiver for data packets is known.

   3.3 Destined receiver replies a CTS packet back to the sender, and other nodes are allowed to sleep without necessarily staying awake in the WithoutDATA period.

Thus, we implement a scheme which can save energy significantly and can work more efficiently.

5. PERFORMANCE MEASUREMENT

5.1 Simulation Setup

We evaluate our DPC-EEFRP scheme through NS2[15] simulation. We considered a random network deployed in an area of 500 X 500 m. The number of nodes is varied as 100,125, 150,175 and 200. Initially the nodes are placed randomly in the specified area. The initial energy of all the nodes assumed as 8 joules. Initial receiving and sending power levels are 0.395 and 0.660 watts. The DPC-EERRP protocol is used as MAC layer protocol. The simulated traffic is CBR with UDP source and sink. All experimental results presented in this section are averages of five runs on different randomly chosen scenarios.

The following table summarizes the simulation parameters used.

Table 1
Simulation Parameters

No. of Nodes	100,125,150,175 and 200
Area Size	500 × 500
Mac	802.11
Simulation Time	50 sec
Traffic Source	CBR
Packet Size	512
Transmit Power	0.395 w
Receiving Power	0.690 w
Idle Power	0.335 w
Initial Energy	8 J
Transmission Range	75m

5.2 Performance Metrics

We compare DPC-EEFRP with the DTPC [7] scheme. We evaluate mainly the performance according to the following metrics.

- **Average Packet Delivery Ratio**: It is the ratio of the number of packets received successfully and the total number of packets transmitted.
- **Average Energy**: It is the average energy consumption of all nodes in sending, receiving and forward operations.

5.3 Simulation Results

We vary the number of nodes from 100 to 200 and measure the above metrics for the two schemes.

Figure 1 shows the results of average packet delivery ratio for the nodes 100 to 200. Clearly our DPC-EEFRP scheme achieves more delivery ratio than the DTPC scheme since it has both reliability features.

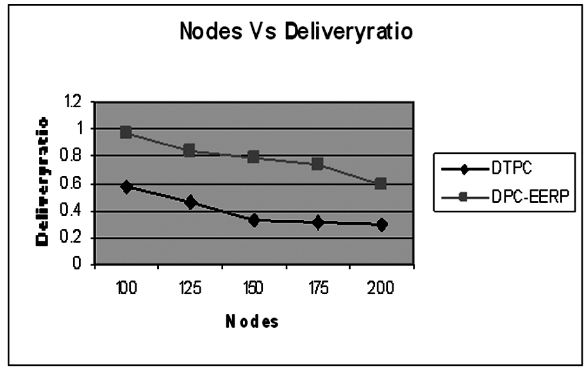

Figure 1: Nodes vs Delivery Ratio

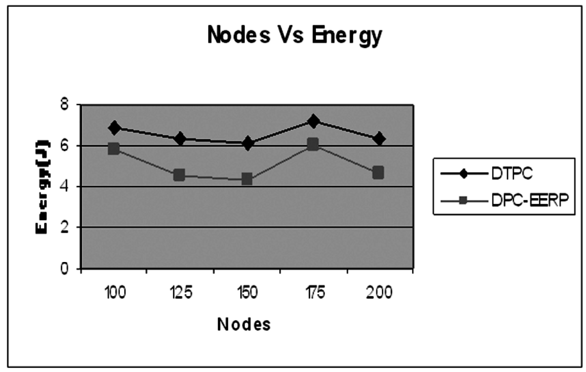

Figure 2: Nodes vs Energy

Finally, we measure the average energy consumption of the network. From Figure 2, we can see that, our DPC-EEFRP consumes less energy when compared with the DTPC.

6. CONCLUSION

In this paper we had developed a power control algorithm with energy efficient reliable routing. For establishing effective transmission power control mechanism, the dynamics between link qualities and RSSI/LQI values were studied. A node with transmission power sends beacons to its neighbors and their neighbors where RSSI and the link quality values were calculated. In order to minimize energy consumption, we have proposed Distributed Power Control Energy Efficient Forwarding Routing (DPC-EEFR) protocol using E3-MAC Algorithm. In the energy efficient forwarding protocol, the data forwarding probability is adaptively adjusted based on the measured loss conditions at the sink In DPC-EERR MAC protocol, all nodes turn off their radios much earlier when no data packet transfer is expected to occur in the networks and it eliminates communication of a separate RTS control packet even when data traffic is likely to occur. This protocol enables continuous data forwarding without incurring energy waste of unrelated nodes.

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