센서 네트워크를 위한 Link-State 정보 인지 Rate Adaptation

(Link-State Information Aware Rate Adaptation for Sensor Networks)

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요 약 : 센서 네트워크에서 병목현상은 패킷 손실을 발생시킨다. 패킷 손실은 네트워크 성능과 처리량을 대폭 감소시킨다. 그리고 간섭현상은 링크 노드와 센서 노드에서 무선 병목현상을 발생시키는 중요한 요소이다. 센서 노드의 에너지 제한 때문에 네트워크의 병목현상을 제거하고, 효과적으로 rate adaptation을 수행하는 것은 중요하다. 이를 통해 node buffer의 overflow를 피할 수 있다. 이 논문에서 우리는 센서 네트워크를 위한 rate adaptation 프로토콜을 제안한다. 이러한 방식은 네트워크에서 Adapting rate를 위한 링크 측의 간섭현상과 노드측의 buffer 점유를 조절할 수 있다. inter-path와 intra-path 간섭현상의 개념을 여기서 사용하였다. 센서를 위한 최소 전송 인터벌을 사용을 함으로써 센서 주변의 링크 효율성을 증가시킬 수 있다.. 마지막으로 실험 결과물에서 제안된 작업의 효율성과 에너지 분석, 네트워크의 처리량에서 좋은 성능을 보여주는 것을 알 수 있다.

키워드 : Wireless Sensor Network, Rate Adaptation, Congestion, Interference etc.

Abstract: **In a sensor network bottleneck scenario usually causes packet loss which in turn drastically decreases network performance and throughput. Moreover interference is an important factor for wireless network bottleneck. As sensors are energy constraint, so it is a decisive task to remove network bottlenecks using efficient rate adaptation so that node buffer overflow can be avoided. In this paper we proposed a rate adaptation protocol for sensor network. This approach mainly handles link level interference and node level buffer occupancy for adapting transmission rate in the network. Concept of both intra-path and inter-path interference are used here. Here it is shown that wireless link utilization around a sensor can be increased by the efficient use of a new metric *Minimum Transmission Interval* for each of the sensors. Finally experimental outputs have demonstrated the effectiveness of the proposed task and show a noticeable performance in terms of energy analysis and throughput of the network.**

Keywords: Wireless Sensor Network, Rate Adaptation, Congestion, Interference etc.

1. Introduction

Due to shared nature of the wireless medium all sensor nodes in a sensor network contends for medium access. Thus observing in network bottleneck scenario is expected, which results drastic decrement in overall network throughput. Interference is a source of causing bottleneck for sensor networks and it includes both Inter-path interference and Intra-path interference [1]. These interferences may cause severe performance degradation and reduce link utilization due to concurrent data transmission between wireless links. Therefore solutions are required to remove bottleneck scenarios from sensor networks by efficiently handling interference.

In a multi hop and multi path communication model of sensor networks, intermediate nodes and wireless links carry disproportionately large amount of traffic. Thus shortage of buffer space appeared if nodes can not get sufficient access to the wireless medium and thus resulting obvious decrement in service rate. It radically consumes huge amount of energy as well as causes packet loss and delay. Moreover in CSMA [2] like protocol, contention could carry out over long time and produce the same results of decrementing service rate for a node. Therefore, rate adaptation mechanism seems to be an effective and apparent solution to this problem having awareness of both wireless link and node buffer occupancy.

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In this paper, an interference aware rate adaptation mechanism for sensor network is proposed. Link level rate adaptation is proposed here evolving a new metric *Minimum Transmission Interval* for each starting node of a wireless link. On the other hand, node level rate adaptation is performed using a safe buffer occupancy approach for each of the sensor nodes.

The rest of this paper is organized as follows: section 2 presents several background studies on rate control and adaptation techniques in sensor network. Subsequently section 3 describes protocol assumptions and some useful definitions. Section 4 represents our proposed scheme in detail for both link and node level rate adaptation. Section 5 has gone through some experimental results with simulation efforts and explanation. Finally section 6 concludes this paper.

2. Related Work

In this section, our background studies on various aspects of previous rate adaptation mechanisms, their effects and techniques are cited. We made few design considerations from these cited works.

Here, we mainly categorized the previous related works depending on the awareness of interference. The very early interference aware rate allocation method is IFRC [3]. It is a distributed rate allocation scheme where each sensor nodes share the congestion through overhearing. It converges to allocate an optimal and efficient rate for each of the sensor nodes. QCRA [4] is rate allocation scheme, sink node is responsible to assign individual rate for each sensor nodes. Parameters consider in this solution are topology information, routing information and link loss rate information. A very recent work Flush [1] implemented a novel pipelining mechanism for dynamic rate control for sensor network. In this approach only one node is permitted to transmit a data packet on a given time within the same interference range.

Among the previous protocols those do not take interference in to their consideration, the very first protocol is ESRT [5]. It is a centralized sink initiated rate control protocol for event driven applications and in this approach all nodes in the network are considered to be within one hop away from the sink. CODA (Congestion Detection and Avoidance) [6] is another rate control protocol for the upstream sensor nodes. Each of the nodes in the network controls their rate using AIMD fashion. Fusion [7] can be found as an efficient congestion control mechanism. It studies three approaches namely; hop-by-by flow control, source limiting scheme and prioritized MAC, operate at different layers of the traditional protocol stack.

3. Assumptions and Useful Definitions

3.1. Network Model

In this paper we particularly give emphasize on the rate adaptation for a sensor node. In multi hop wireless communication, inter-path interference is quite common while more than one wireless link interfere with each other. On the other hand, intra-path interference [1] takes place within a single path, where one transmission cannot take on an upstream link due to the interference from its up and downstream links respectively.

Figure 1: Inter and Intra Path Interference Scenario

In Figure-1 inter-path Interference are on link (e,f), (g,h) and Intra-path Interference on link (j,k), (Source, i), (k, Destination) respectively due to a ongoing transmission on link (i,j).

Depending on the general architecture of the sensor network model, all subsequent discussions are based on the CSMA-like MAC [2] standard. Both single path and multipath routing are used where paths are pre-established from sources to the sink. Sensor nodes are battery operated with limited power and they are static. Each sensor node piggyback the control information; i.e. transmission interval, average buffer size respectively for each time epoch etc.

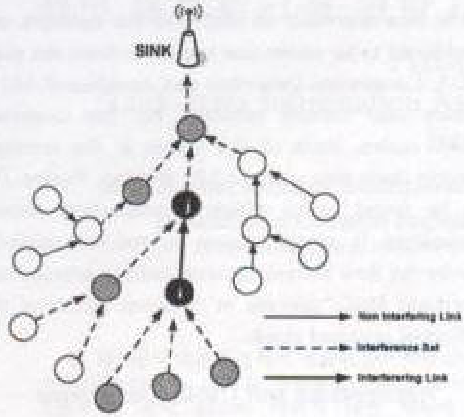

Figure 2: Interference Set for link (i,j)

3.2. Definitions

In the sub sequent sections of this paper we consider the following definitions and this work as the basic assumptions of the proposed protocol.

Definition 1: Given a buffer at each sensor node, *normalized average buffer size* is the average buffer length at each epoch time t. It is denoted as avg_i^t for a sensor node i and normalized to 1.

Definition 2: Suppose, a network $G(N,L)$, where a set of active links $(i,j) \in L$ transmits data. All transmission initiates/directed from the node i to node j and (i,j) is said to be active when node i is backlogged.

Definition 3: Let, one link (i,j) connects node i and j. Like [9], we define $Inf(i,j)$ as the interfering set of (i,j). $Inf(i,j)$ includes all the links whose atleast one endpoint is at interference range of either i or j or both (including link (i,j) in Figure 2).

4. Proposed Scheme

4.1. Link Level Rate Adaptation

In [9] a channel busy time (CBT) is defined as the amount of time interval for which the wireless channel is busy. Here we define a term transmission interval $I_{(i,j)}$ for each link (i,j) (also called transmission interval of node i on link (i,j)). In a single epoch time t, $I_{(i,j)}$ includes transmission of data packets from node i, reception of that packets at node j, transmission/reception time of each of the links of interfering set $Inf(i,j)$.

The main target here is to minimize collision between sensor nodes. In the proposed scheme we derive a metric *Minimum Transmission Interval* (τ_i) for each node i to transmit data on the link (i,j):

$$\tau_i = Max(I_{(k,l)}); \quad \forall(k,l) \in Inf(i,j)-(i,j)$$

In fact τ_i is the maximum transmission interval among all the links of interference set $Inf(i,j)$ except link (i,j). Each node i will overhear the transmission interval values of other nodes whose corresponding link is in interference set $Inf(i,j)$.

4.2. Node Level Rate Adaptation

Proposed scheme also comprise node level rate adaptation considering buffer occupancy at each sensor node. The basic idea is adopted from the traffic engineering theory [10] and another wired line scheme [11]. We perform modifications in order to use those approaches for our purpose.

Let, r_t is the rate of a node to be calculated at the current epoch t. Thus the basic rate adaptation equation for node i can be formulated as:

$$r_t = r_{t-1} + \varphi_i \quad \text{Such that, } \tau_i = TRUE$$

Where φ_i used as the rate increase/decrease parameter of node i and it is derived from:

$$\varphi = avg_j^{(t-2)} - avg_j^{(t-1)}$$

Here, $avg_j^{(t-1)}$ and $avg_j^{(t-2)}$ are the *normalized average buffer size* of the immediate downstream node j on epoch $(t-1)$ and $(t-2)$ respectively.

5. Simulation

Simulations are performed in order to derive the performance of the proposed scheme. The simulation parameters are described as follows: 100 sensors are randomly deployed in 250x250 m^2 sensor field. Receiving distance and sensing distance considered to be 40 meters and 80 meters respectively. Interference distance of a node is double than the sensing distance.

5.1. Energy Analysis

Average residual energy of each node of the network was traced out and at the end of simulation we plot average residual energy distribution of the network in Figure 3. We analyzed and make a comparison with a scheme where no rate adaptation is performed.

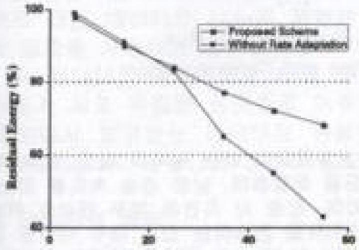

Figure 3: Energy Consumption Scenario

5.2. Throughput Analysis

The overall network throughput (normalized to 1) between proposed scheme and without rate adaptation scheme is depicted in Figure 4. It shows a better result in comparison.

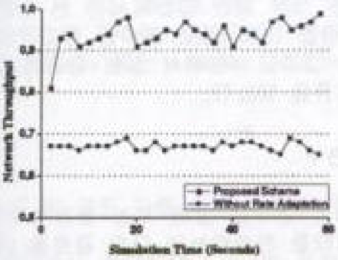

Figure 4: Network Throughput Scenario

6. Conclusions

Due to the random access of the medium, both link level access varies over time as well buffer occupancy also varies significantly. In sensor networks, these two reasons might cause less network throughput and huge energy consumption. This paper addresses the same phenomena and tried to find possible solution for both link level and node level rate adaptation. This scheme is verified to be energy-efficient and can greatly increase the network throughput.

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