Congestion Detection and Control Strategies for Multipath Traffic in Wirel ess Sensor Networks

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요 약

This paper investigates congestion detection and control strategies for multi-path traffic (CDCM) diss emination in lifetime-constrained wireless sensor networks. CDCM jointly exploits packet arrival rate, succ essful packet delivery rate and current buffer status of a node to measure the congestion level. Our objec tive is to develop adaptive traffic rate update policies that can increase the reliability and the network lif etime. Our simulation results show that the proposed CDCM scheme provides with good performance.

1. Introduction

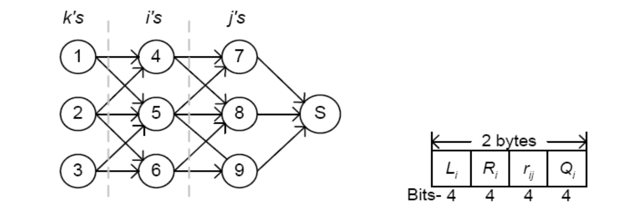
The multipath traffic forwarding, from a group of sensor nodes to the base station (sink), can greatly increase the network lifetime as well as the application reliability [1][3]. However, simultaneous occurrence of multiple events may produce huge amount of traffic and increase the congestion level, which in turn may jeopardize the network goals [1][2]. In this paper, we design distributed and adaptive schemes for (i) accurate detection of incipient congestion and (ii) congestion control strategy that judiciously uses the available bandwidths of the alternate links in presence of congestion. We design our schemes on a tree-based multipath forwarding (MTF) routing protocol [3] and legacy 802.11 DCF MAC. The proposed CDCM scheme outperforms the existing works.

2. Network Model and Assumptions

We consider a sink-rooted tree-based network architecture. Sensor nodes and the sink are static after the deployment. All nodes have the equal transmission range (R_{tx}). We assume that all data packets have the same size and the buffer size of a node is counted as the maximum number of data packets that it can hold. The underlying routing protocol uses multi-path traffic forwarding (MTF) [7]. Note that in case of MTF, the total traffic load of any node i may be distributed over a set of downstream nodes D_i, which are the next hop nodes (j's) on the routing paths from i to the sink, S. Similarly, if U_i represents i's set of upstream nodes, each node k,($k \varepsilon U_i$) uses i as next hop node on its routing path. Fig. 1(a) shows the above relationships.

3. Congestion Detection and Control Strategies

Each node i measures/estimates the aggregated traffic load it has to handle (L_i), successful packet delivery rate (SPDR) towards each next hop downstream node (rij) and thereby aggregated SPDR of the node (Ri). While node i forwards a data packet to its next hop, it appends Li, Ri, rij and Qi in the MAC header of the packet, as shown in Fig. 1(b), where Qi represents the number of free buffer spaces in the node. Nodes in the set Ui learn the values of above parameters by



(a) Multipath data packet forwarding (b) Additional fields in the MAC header

Fig. 1. Multipath data packet forwarding and new fields in MAC header

overhearing the packet and independently execute the congestion detection and control strategies.

3.2 Input Traffic Load Measurement

In case of multi-path routing, each node divides its total traffic into multiple traffic flows and those flows pass through multiple downstream nodes. Therefore, the aggregated traffic load of an intermediary node i (L_i) is the sum-total of the data packet rates (in packets per second, pps) of its all upstream traffics plus its own data packet generation rate (g_i), and is expressed as follows

$$L_i = (\sum_{k \in U_i} r_{ki}) + g_i \quad (1)$$

Note that a simple distributed algorithm can compute the aggregated traffic loads of all nodes iteratively.

3.3 Successful Packet Delivery Rate Estimation

The ability to route optimal amount of traffic to candidate receivers at intermediate hops is very beneficial to improve reliability and efficiency. To cope up with the time-varying characteristics of sensor network links, we measure the success rate of each link (i,j) using windowed mean and then use EWMA (exponential weighted moving average) formula to more accurately estimate the link rates.

Let W be the constant size of a window and t_k be the total time required to transmit all the packets of k^{th} window, and it is measured as the time interval between the end of successful delivery of the last packet of $(k\text{-}1)^{th}$ window and that of k^{th} window. It includes backoff time, collision resolution, and packet transmission and retransmission times.

This work was supported by the IT R&D program of MKE/KEIT. [2009-S-014-01, On the development of Sensing based Emotive Service Mobile Handheld Devices]. Dr. Choong Seon Hong is the corresponding author.

Therefore, the instantaneous successful packet delivery rate for k^{th} window is calculated as follows-

$$r_{ij}(W_k^j) = \frac{W_k^j}{t_k}, \quad \forall i, j \qquad (4)$$

where, W_k^j represents the number of packets of k^{th} window that are successfully delivered to the downstream node j. Note that W_k^j<W, and the equality condition holds true whenever the link quality is very good, and vice-versa. Now, on completion of each window of packet transfer, we execute the following EWMA equation that estimates the successful packet delivery rate over time.

$$\hat{r_{ij}}(W_k^j) = (1-\alpha) \times \hat{r_{ij}}(W_{k-1}^j) + \alpha \times r_{ij}(W_k^j) \quad \forall i, j \qquad (5)$$

Since EWMA takes the historical behavior into account, we believe that the successful packet delivery rate of a link could more accurately be predicted by Eq. (5). Through empirical evaluation and extensive simulation, we have found that setting alpha = 0.2 produces the best estimation.

Therefore, the estimated successful packet delivery rate of node i at time t, $R_i(t)$, is the sum-total of the estimated packet delivery rates towards all downstream nodes and is calculated as follows

$$\hat{R}_i(t) = \sum_{\forall j \in D_j} \hat{r_{ij}}, \quad \forall i \qquad (6)$$

3.4 Congestion Detection and Control

Based on the above information, any CDCM node i can determine a congested state using the following rules:

Rule 1: R_i/L_i fall below a threshold value (e.g., 0.8).

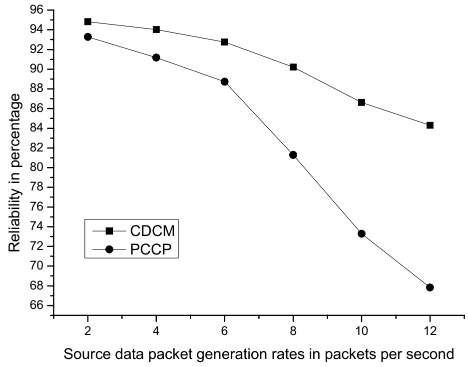
Rule 2: R_i/L_i is in between 0.8 and 1.0 but Q_i falls below its threshold value (e.g., 5); otherwise no congestion.

Because the buffer threshold at which triggering occurs is fixed, queue-based detection methods coupled with the ratio of arrival rate and service rate can be a suitable congestion detection mechanism preventing packet drops better. Such a mechanism is believed to tackle both the long bursts and sporadic bursts of traffic efficiently.

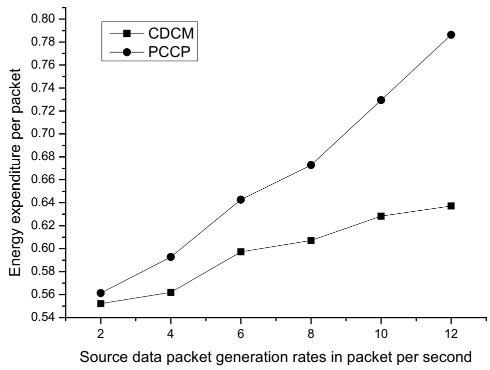
When a node i detects that it is congested, it sends a congestion notification message to the upstream node which is forwarding most traffic. Any node $k \varepsilon U_i$ receives this congestion message will repeat the above procedure in the case it is also congested; otherwise, it becomes the traffic distributor. It then diverts traffic from $j \varepsilon D_i$ to an idle downstream node. If no such alternative node is found, the node i must decrease its traffic forwarding rate through that downstream node to half.

4. Simulation Results

The effectiveness of the proposed schemes is evaluated in ns-2.30[4] and the proposed CDCM scheme is compared with PCCP [1]. The simulation parameters are described as follows. The terrain size is 1000mX1000m, where 1000 sensor nodes are uniformly distributed. The sink node is located at [1000, 500] location. Each sensor's transmission and sensing radii are 100m and 50m, respectively. The payload amount of each data packet is 64 bytes and the buffer size of each node is 30. The link data rate is 512Kbps. 100 sensor nodes are randomly picked as data source and the simulation is run for 10 seconds.



(a) Delivery ratio



(b) Energy expenditure

Fig. 2: Performance evaluation results

As shown in Fig. 2(a), the proposed CDCM scheme can maintain much higher delivery ratio even at increased traffic generation rates as compared to PCCP. This is due to its novel congestion detection and control strategies. CDCM also takes much less energy per successful delivery of data packets to the sink, as shown in Fig. 2(b). This is happened because CDCM reduces the packet drops significantly and cleverly uses the lightly loaded paths for data dissemination.

5. Conclusion

The proposed CDCM mechanism works autonomously with a minimum of administrator oversight and improves the performance by a significant amount.

References

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