論 文 の 内 容 の 要 旨

論文題目　Token-Scheduled Data Collection in Wireless Sensor Network
（無線センサネットワークにおけるトークン利用型データ収集方式）

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Along with the increasing interest in capturing fine-grained information from the physical world, wireless sensor networks have drawn intense attention in recent years. One of the most important functions provided by wireless sensor networks is data collection. The efficient data delivery in wireless sensor network is limited by potential interference and limited bandwidth. Concrete applications also have requirements in terms of collection reliability, adaption to network changes, etc.

This paper aims for realization of high throughput, topology adaptability, real-time and reliability. The pursuit of high throughput data, topology adaptability, real-time and reliability is especially required by applications like volcanic activity monitoring. Such applications are deployed under harsh environmental conditions and need large size data transfer. They tend to focus more on high network throughput, low collection delay and high delivery ratio, as opposed to energy efficiency. One such example is the air-dropped volcanic monitoring sensor network: one sensor node generates 440~bytes per second. Since such sensor networks are deployed under harsh environmental conditions, both software and hardware failures are difficult to be avoided. Node failures cause network topology changes. Therefore, the system should be developed to be resilient to topology changes. The system should also be able to provide low delay collection with high delivery ratio, i.e. reliability according to the application requirements.

Toward realization of high throughput, topology adaptability, high delivery ratio and real-time collection, there are two dilemmas.

First, there is a dilemma between high throughput and topology adaptability. Although CSMA is suitable for realization of topology adaptability, it is inefficient in achieving high throughput due to the constant medium probing. In contrast, the contention-free medium access control protocols based on TDMA are more suitable for high throughput data collection. Yet, topology adaptability is an open issue for TDMA. The scheduling burden of traditional TDMA is complex in wireless sensor network. Since traditional TDMA endeavors to assign a fixed transmission time slot to each sensor node, the rescheduling task is heavy upon network changes, especially for the centralized TDMA that needs to reassign time slots for all of the sensor nodes.

Different from existing works, this paper assumes uniform traffic, which makes sense because the traffic patterns of most data collection applications are uniform. Energy efficiency in terms of duty cycle has also not been considered since applications like volcanic monitoring are endurable in keeping radio always on.

Under the premises, this paper proposes TKN-TWN: token based multi-channel TDMA to tackle the dilemma between high throughput and topology adaptability. Two features characterize the design of TKN-TWN: (1) TKN-TWN arbitrates burst data transmission using multiple tokens. (2) TKN-TWN leverages multi-channel TDMA for efficient packet forwarding, where time slot assignment is further associated with the token ownership for throughput optimization. The time slot assignment in TKN-TWN is self-determined based on routing information. As a result, topology adaptability in TKN-TWN only involves robust token passing and routing recovery. TKN-TWN is able to conditionally break the myth that TDMA does not adapt well to topology changes and maintain high throughput as well.

Second, there is a dilemma between reliability and real-time. In order to provide reliable data collection, end-to-end packet loss recovery is needed. To this end, the sink node has to deliver the lost packets’ information to related sensor nodes. However, implementation of downward communication from sink node to source node is difficult for high throughput data collection due to the limited bandwidth. Therefore existing works such as PIP and Flush use flow to provide bi-direction communication between two end points of sink node and source node, which involves flow setting up and tearing down. Such approaches are suitable for bulk data transfer in applications like structure health monitoring that normally requires one-shot short term data collection. But since the flow setting up and tearing down causes delay to data collection, connection-oriented data collection using flow is not suitable for applications like volcano monitoring that requires long term consistent real-time data collection.

Toward realization of reliability, TKN-TWN exploits the bi-direction token passing for end-to-end packet loss recovery, which affords TKN-TWN the leverage to achieve high delivery ratio with connection-less communication. The sink node piggybacks lost packets' information on token messages. When distributing tokens in a new collection round, the sink node loads the lost packet's information on the token messages. Upon tokens' arrival, source nodes check and retransmit the lost packets in the first place. Since token based scheduling is not connection-oriented, low delay data collection can be achieved. Considering that the piggyback capacity of one single token message is limited, Token-Burst is also proposed to flexibly extend the piggyback capacity when needed.

Token passing brings out overhead, but the overhead is tolerable in case of burst data transmission under uniform traffic pattern. Under uniform traffic pattern, each token passing from a parent node to a child node in TKN-TWN is able to trigger burst data transfer. The duration of the token passing is small compared with that of the burst data transfer upon a token's arrival. As a result, high collection throughput can be maintained even with token passing overhead. In contrast, under non-uniform traffic pattern tokens might travel longer periods among sensor nodes before the next potential burst data transfer can be triggered, so that the collection throughput is reduced.

The author implements TKN-TWN on Tmote Sky with TinyOS 2.1.1 operating system. Analysis regarding the token passing and collection throughput is given. Evaluation verifies the analysis and shows that TKN-TWN is able to provide throughput of 9.7 KByte/s. The experimental results in a deployed network consisting of 32 sensor nodes show that TKN-TWN is robust to network changes caused by occasional node failures. 100% data collection has been achieved in the experiment. To the best knowledge, this work is the first to consider reliable high throughput data collection with topology adaptability and low delay using token-based scheduling.