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CoCo$^+$: Exploiting correlated core for energy efficient dissemination in wireless sensor networks

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ABSTRACT

Bulk data dissemination is a basic building block for enabling a variety of applications in wireless sensor networks such as software update, network bug fixing, surveillance video distribution, etc. The recent structure based approach looks promising for efficient dissemination since it facilitates transmission and sleep scheduling. However, a number of limitations exist in existing structured protocols. In this paper, we propose a correlated core based solution for efficient bulk data dissemination in wireless sensor networks (called CoCo$^+$). CoCo$^+$ has three salient features. First, CoCo$^+$ is based on an efficient node selection algorithm for constructing the core structure by exploiting link correlation (called Correlated Core). Second, CoCo$^+$ employs a novel consecutive transmission mechanism, which allows out-of-order transmissions and reduces propagation delay. Third, CoCo$^+$ uses a novel lightweight negotiation mechanism that greatly reduces negotiation overhead as compared to the existing structured protocols. We implement CoCo$^+$ with TinyOS/TelosB and conduct both simulation and testbed experiments. Results show that our proposed solution outperforms the state-of-the-art by 52.3 and 49.6% in terms of the number of transmissions and the completion time, respectively.

1. Introduction

A wireless sensor network (WSN) is composed of a large number of small, inexpensive sensor nodes that integrate sensing, computation, and wireless communication capabilities [1]. Bulk data dissemination is used to distribute a large data object reliably to all network nodes in a multi-hop manner. It is one of the key enabling techniques for many WSN applications (e.g., software deployment, reprogramming, surveillance video distribution, etc. [2] [3]) and has attracted much research attention [4–11]. Dissemination has the following requirements: (1) full reliability. Due to that data dissemination is often used for software update, command distribution, etc., each node is required to receive the data object in its entirety. (2) energy efficiency. We regularly face the requirement for software update and maintenance. For example as reported in [12], the software version increases from 158 to 285 during Dec. 2010–April 2011. Therefore, the energy efficiency of dissemination has a large impact on the network lifetime. (3) low latency. Since dissemination is often used for software update, during which the network would be temporarily down, the dissemination should be done as soon as possible. Due to the above requirements, most existing dissemination protocols segment a large data object into several pages for a page-by-page, pipelined transmission. A three-way handshake (ADV-REQ-DATA) protocol is typically used to ensure data consistency.

According to the propagation manner, existing work can be basically divided into two categories: structureless and

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structured protocols. Structureless protocols [5,7] use simple flooding for data propagation from the sink to all network nodes. Differently, structured protocols [9,10] establish a network core structure before data dissemination. Such structure can be, for example, Connected Dominating Set (CDS) employed in CORD [10]. Data dissemination is first done by propagating the data object to all the core nodes, each core node then disseminates the object to their neighboring nodes. Structured protocols explicitly select the set of core nodes which are responsible for forwarding the data object to the rest of the network, and data propagation can be done in a more efficient way by appropriate transmission and sleep scheduling. They introduce less broadcast overhead as compared to structureless protocols that are prone to the broadcast storm problem. Hence, it offers a good solution for dense and low-power wireless sensor networks.

In nutshell, core structure construction, data transmission and negotiation are three fundamental building blocks of structured dissemination. However, a number of limitations exist in all the three building blocks in the existing structured protocols. First, the core constructions fail to consider link correlation. Link correlation is often identified as the correlation of packet receptions on different links [13]. For example, if two links are strongly correlated, we can infer that when one link's receiver receives/loses a packet, the other link's receiver is much likely to receive/lose that packet. Link correlation has shown a great impact on the efficiency of broadcast, i.e., transmissions are more efficient when link correlation is stronger [13–15]. Existing structured protocols ignore link correlation when selecting the core nodes. As a result, the selected core nodes may have poor link correlation, which can seriously affect the transmission efficiency. While link correlation has been effective to achieving more efficient flooding [14] [15], no existing work has been done to exploit link correlation for structured dissemination in wireless sensor networks.

Second, the existing page-by-page reliable transmission mechanism is not efficient. In CORD, the state-of-art work, a sender has to deliver an entire page to its receivers before transmitting the next page. As wireless links are usually unreliable, a page may need multiple transmission rounds to be fully delivered. For example, a sender tends to transmit 10 pages (each page consists of 10 packets) to a receiver with link quality of 90%. The first round transmits 10 packets among which one packet is lost. In the second round, it only re-transmits the missing packet. As a result, it takes two rounds to transmit a page. In total, there will be 20 transmission rounds, with 10 rounds transmitting 10 packets each and another 10 rounds re-transmitting only one packet each. The problem lies in re-transmission which is less efficient. Obviously, it needs more transmission rounds which (1) increase the propagation delay, (2) and also incur more negotiation overheads. Ideally, if we can combine the re-transmissions for the missing 10 packets into one transmission round, it would be much efficient.

Third, the three-way handshake mechanism (ADV-REQ-DATA) may incur considerable message overhead in structured protocols. (i) the ADV messages are originally designed for discovering neighbors and data packets when there are no underlying structures. It becomes necessary as in structured dissemination, each node has a fixed parent and child nodes and always receives data packets from its parent. (ii) when a node receives ADVs and identifies useful data, it will prepare an REQ message. Before the REQ transmission, a back-off timer is used to avoid possible collisions. However, existing REQ back-off timer is set to be constant, e.g., 256 ms for CORD. It may incur large delay overhead in sparse networks and severe REQ collision in dense networks.

To address the above limitations, in this paper, we propose CoCo$^+$, an energy efficient bulk data dissemination protocol built on CoCo [16], that efficiently cope with the above limitations using three separate improving approaches. First, inspired by recent works on link correlation [15,17], we formally model the relationship between expected number of transmissions (ETX) and link correlation when establishing the core structure. Nodes with strong link correlation and better link quality are more likely to be selected. As a result, the transmission overhead can be reduced. Second, we propose a novel transmission mechanism to reduce both propagation delay and redundant transmissions. For each transmission round, we allow out of order transmissions. Instead of sending only the missing packets from last page, we top up a full page-size batch with more packets from the next pages for transmission. In this way, we make use of each transmission round more efficient. Third, we optimize the three-way handshake by eliminating ADVs and employ an adaptive back-off timer to avoid REQ collisions as well as reduce delay under different network densities. It is worth noting that CoCo$^+$ reserves the coordinated transmission/sleep scheduling in CORD [10]. We implement CoCo$^+$ in TinyOS and evaluate its performance by extensive experiments and simulation. The results show that CoCo$^+$ outperforms the state-of-the-art work by 52.3 and 49.6% in terms of the number of transmissions and the completion time, respectively.

In summary, the paper makes the following contributions.

1. We design a core construction algorithm for more efficient transmission, which exploits link correlation to accurately estimate a potential sender's expected number of transmissions (ETX), and select the nodes with small ETX as core nodes.
2. We propose a novel consecutive transmission mechanism, which can transmit packets in an out of order fashion, and effectively reduces the propagation delay.
3. We optimize the three-way handshake mechanism in structured protocols, reducing the negotiation message overhead and REQ collisions with different network densities.

The latter two contributions are the main differences of CoCo$^+$ from the conference version CoCo [16]. The rest of the paper is organized as follows: Section 2 introduces the related work. Section 3 describes the motivation of this work by two examples. Section 4 describes the key improving mechanisms in CoCo$^+$. Section 5 gives the detailed design of CoCo$^+$. Section 6 reports the evaluations by comparing its performance with both CORD and Deluge. Section 8 concludes our work.