Power Efficient Data Communication Strategies for Wireless Sensor Networks

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論文内容要旨

Due to the power constraint, it is very important to save the power of the sensors so that the batteries of the sensor nodes last for long time. Our main objective is to find new opportunities for saving more power for sensor nodes, such that the lifetime of the overall WSN is prolonged. In order to achieve our objective, in this thesis, we attempt to solve the power waste problems due to unnecessary power consumption actions in data communication. This study mainly focus on how to introduce a data communication approach and how it can be done in delay performance and a power efficient way. In this thesis, we propose a power efficient data communication protocol for WSNs which can reduce the delay, transmission cost and maximizing the lifetime of whole sensor network. Critical to any WSN deployment is the expected lifetime. The contribution mainly lies in following three aspects.

Firstly, we improve the efficiency of data distribution protocol by proposing neighbor discovery mechanism through network coding. The existing data distribution protocol, AdapCode, is weak in neighbor discovery which is the most essential part in coding process. With our proposed method, we could improve the coding opportunities and thus the lifetime of the sensor network is extended by 25% to 35%.

Secondly, we propose to use the digest information of the subsequent data packets to reduce the power waste by overhearing and idle listening. We not only reduce the power waste for idle listening, but also reduce the power waste of overhearing irrelevant broadcast packets during data distribution process. In this way, the lifetime improvement can be up to 40% to 50%.

Finally, we propose two types of buffer management schemes for multi-layer WSNs. Unlike the conventional WSNs which consider the whole network as single layer, we divide sensor network topology logically into multiple layers according to the type of sensors' readings. Sensors in multi-layer WSN type-A accommodate to listen the packets originated from other layer sensors while that competence is not considered in multi-layer WSN type-B. Our proposed schemes can reduce the relevant packet loss and power waste for retransmission of packets loss.

Wireless sensor networks (WSNs) are composed of sensor nodes, which are typically highly constrained devices with low computational power and a small memory size. Applications shall be designed to work for months or even years without changing the battery of the sensor nodes. Therefore, power-efficiency is a crucial requirement for applications implemented on sensor nodes. In addition, a long delay is also highly undesirable for time-sensitive applications such as critical situation monitoring and security surveillance. Our main objective is to find new opportunities for saving more power for sensor nodes, such that the lifetime of the overall sensor network is prolonged. In order to achieve our objective, in this thesis, we propose a power efficient data communication protocol for WSNs which can reduce the transmission cost and maximizing the lifetime and delay performance of whole sensor network by solving the power waste problems due to unnecessary power consumption actions in data communication.

The thesis is organized into five chapters.

Chapter 2 provides the background information on WSNs. In this chapter, first, we discuss the characteristics of a sensor node and constraints in WSNs in detail. We then discuss about the most important issue in sensor network, power consumption issue and then discuss about general approaches to power saving.

In Chapter 3, we present the methods designed for neighbor discovery and sleep-wake scheduling in data distribution protocol which minimize the number of data communication. Firstly, we improve the efficiency of data distribution protocol by proposing neighbor discovery mechanism through network coding. In our proposed scheme, neighbor nodes are discovered by the use of the network beacons. In the initial of neighbor discovery process, each sensor broadcasts a specific number of beacon messages to advertise its presence. Due to the broadcast nature of radio communication, each sufficiently closed neighbor receives this message and infers that it is a neighbor of the sender. Each node maintains a local neighborhood table and during the neighbor discovery process, the identity of the discovered node is added to the table. With our proposed method, we could improve the coding opportunities and thus the lifetime of the sensor network is extended by 25% to 35%. The 'digest info' is a small frame embedded in the wakeup message and sent right before each data broadcast message. Secondly, we propose to use the digest information of the subsequent data packets to reduce the power waste by overhearing and idle listening. We not only reduce the power waste for idle listening, but also reduce the power waste of overhearing irrelevant broadcast packets during data distribution process. In this way, the lifetime improvement can be up to 40% to 50%.

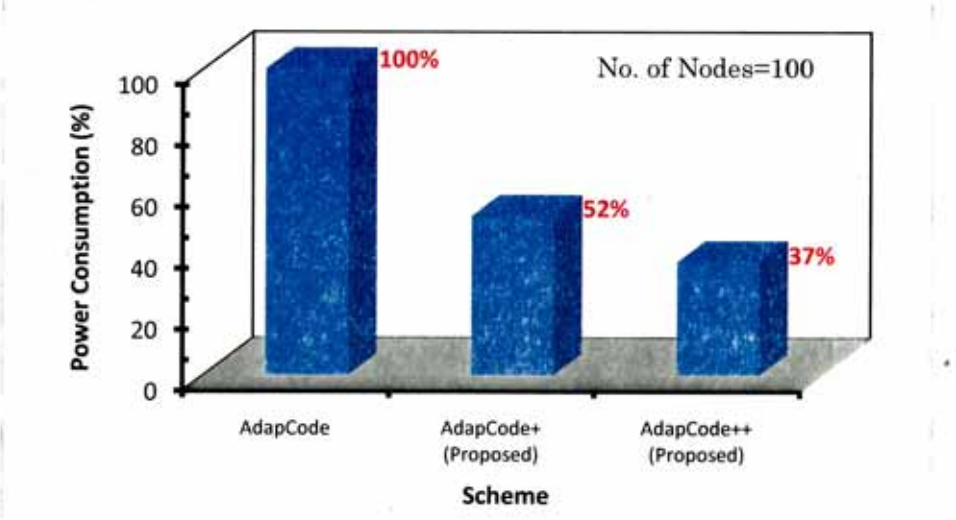

Figure: Comparison of Power Consumption.

Chapter 4 presents a buffer management scheme for multi-layer WSNs. We propose two types of buffer management schemes for improving lifetime and delay performance in multi-layer WSNs. Unlike the conventional WSNs which consider the whole network as single layer, we divide sensor network topology logically into multiple layers according to the type of sensors' readings. Sensors in multi-layer WSN Type-A accommodate to listen the packets originated from other layer sensors while that competence is not considered in multi-layer WSN Type-B. Both proposed schemes, Type-B and Type-A can reduce power waste for retransmission of packets loss 2.8 times and 2.6 times than the conventional scheme respectively. Type-A is better for the delay-sensitive sensor network applications since it can reduce the delay by 75% than Type-B. Finally, we conclude and discuss the future work in Chapter 5.

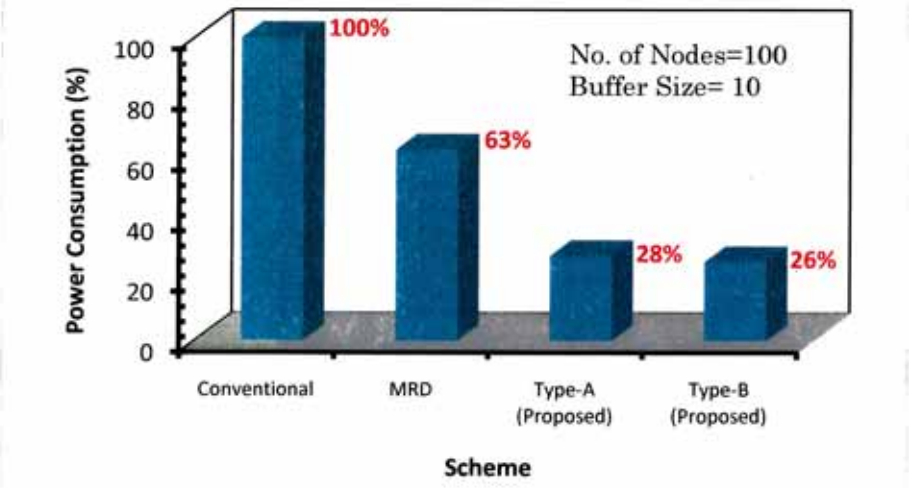

Figure: Comparison of Power Consumption.

Performance results show that our proposed schemes can reduce the significant power consumption in data communication of WSNs. As a main contribution of our thesis, we showed that, network lifetime can be significantly extended by reducing the unnecessary power wastes. The objective of this thesis is to propose a power efficient data communication scheme for the wireless sensor networks. We achieved our objectives by reducing some sources of power wastes such as avoiding overhearing, idle listening, buffer overflow and reducing number of packet transmission. We summarize our achievement as follows:

- Firstly, we considered for the packet transmission problem which is the most power consumption action for sensors' radios. From our observation of the AdapCode data distribution protocol, we found that the actual number of neighbor nodes is very important for the coding benefit in code distribution process. By using our proposed neighbor discovery protocol, we could find out all neighbors (including *semi-active* neighbors) and thus we got more coding opportunities and as a result, it can reduce the number of packet transmission.
- To solve the problem of overhearing and idle listening, we then enhanced our data distribution scheme by proposing a new idea of using digest information of the subsequent data packets. With the help of our proposed 'digest info' field, sensor nodes can envisaged and avoid from receiving irrelevant broadcast packets.
- Finally, to solve the buffer overflow problem, we proposed a new buffer management scheme for wireless sensor networks. In our proposed scheme, we divide the sensor network topology logically into multiple different layers and each

layer is associated with different information collected from its sensing environment. We showed that our proposed multi-layer WSN can reduce the relevant packet loss and power waste for retransmission of lost packets.

From our performance results showed in this thesis, we can conclude that our objective of designing power efficient data communication strategies for wireless sensor networks has been achieved.

論文審査結果の要旨

無線センサーネットワークは，低演算量で低記憶容量の多数のセンサーノードで構成され，これらセンサーノードはバッテリーを交換することなく長期間にわたって動作することが要求されている．このため，ネットワーク寿命を延長するための省電力化は極めて重要な技術課題となっている．本論文は，無線センサーネットワークのための電力効率に優れたデータ通信戦略に関する一連の研究成果をまとめたもので，全編5章から成る．

第1章は緒論であり，無線センサーネットワークの制約と課題を整理し，本研究の目的を述べている．

第2章では，省電力化に関するこれまで行われた研究を紹介し，更なる省電力化技術の導入の重要性を指摘している．

第3章では，ネットワーク符号化を用いるコード配信フェーズにおいてデータ転送回数を低減する隣接ノード発見とノード無線機能休止について検討している．まず，隣接ノード発見処理の初めに各ノードからビーコンを送信して，受信したビーコンより隣接ノードを識別し隣接ノードテーブルを更新する隣接ノード発見法を提案している．提案法がコード配信フェーズの電力消費を従来の52%まで削減できることを計算機シミュレーションにより明らかにした．次に，パケットの先頭に要約情報を付加し，これを利用して無線機能を休止することで自ノードに無関係なパケットの転送を避ける省電力法を提案している．これと隣接ノード発見法とを合わせて用いれば，電力消費を従来の37%まで削減できることを計算機シミュレーションにより明らかにした．これらは，電力効率に優れた無線センサーネットワークを実現する上で重要な研究成果である．

第4章では，センサーノードを温度，湿度，気圧などの検出情報毎に異なる層に分けるタイプAとBの2つの多層化無線センサーネットワークを提案している．従来のネットワークでは，データ収集フェーズにおいて全ての検出情報をまとめて一つの層で扱っていたので無駄なパケット転送が発生するが，提案ネットワークでは層情報と優先度をバッファー管理に取り入れることで無駄なパケット転送を避けるように工夫している．タイプ A では他の層に属するパケットの転送を行うものの，自分の層に属するパケットの転送優先度を高くする．一方，タイプ B では，自分の層に属するセンサーのパケットのみを転送する．タイプ A およびタイプ B は，データ収集フェーズの電力消費をそれぞれ従来の 28%および 26%まで削減できることを計算機シミュレーションにより明らかにした．また，タイプ A はネットワーク遅延をタイプ B の 25%まで短縮でき，防災や防犯などのセキュリティ応用に適していることも明らかにした．これらは無線センサーネットワークの設計に大きな影響を与える重要な研究成果である．

第5章は結論である．

以上要するに本論文は，無線センサーネットワークのための電力効率に優れたデータ通信戦略を提案し，それらの有効性を明らかにしたものであり，無線通信工学および通信ネットワーク工学の発展に寄与するところが少なくない．

よって，本論文は博士(工学)の学位論文として合格と認める．