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Dheeraj K. Klair
University of Wollongong

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On the Suitability of RFID Anti-Collision Protocols in Energy Constrained Environments

A thesis submitted in fulfilment of the
requirements for the award of the degree

Doctor of Philosophy

from

THE UNIVERSITY OF WOLLONGONG

by

Dheeraj K Klair
Masters of Engineering (Microelectronics),
Bachelor of Technology (Electronics and Communications)

SCHOOL OF ELECTRICAL, COMPUTER
AND TELECOMMUNICATIONS ENGINEERING
2009

In memory of my mother

Abstract

Radio Frequency Identification (RFID) has revolutionized the asset tracking industry, with applications ranging from automated checkout to monitoring the medication intakes of elderlies. Its wide acceptance and applicability has spurred researchers to create novel RFID applications. One promising development is equipping nodes in a Wireless Sensor Network (WSN) with a RFID reader to create a distributed, self-configuring, ad hoc wireless network for tracking objects with an RFID tag.

A key problem in RFID-enhanced WSNs is the limited battery life of sensor nodes, which imposes a severe energy constraint on communication protocols. To put this into perspective, this thesis shows that the energy consumed by an RFID reader to read a single 96-bit tag is higher than a sensor node transmitting and receiving 96-bits of data. Moreover, in practice, an RFID reader has to read multiple tags in its interrogation zone, all of which may reply simultaneously. As a result, the RFID reader experiences collisions and unnecessary energy wastage that ultimately shortens a WSN's lifetime. For these reasons, it is imperative that a comprehensive study on the energy efficiency of existing RFID tag reading or anti-collision protocols be conducted in order to determine their suitability for use in RFID-enhanced WSNs.

This thesis, therefore, investigates the energy efficiency of Aloha based RFID anti-collision protocols. These protocols have low memory and bandwidth requirements, adaptive to changing tag population, and a small number of reader

to tag commands; thereby, making them easy to implement on sensor nodes. Using analytical and simulation studies, this thesis shows that collisions and idle listening to be the key causes of energy consumption. Idle listening consumes a significant amount of energy, especially when the number of tags is low, but as the number of tags increases, collisions become the main cause of energy expenditure.

Another major finding is that existing anti-collision protocols are unable to monitor tags in an energy efficient manner. Specifically, in order to monitor tags, these protocols must undergo the collision resolution process repeatedly. This problem is particularly acute when tag population changes frequently. Hence, there is a clear need for energy efficient protocols that can determine new and old tags quickly. To this end, this thesis is the first to propose ResMon, an anti-collision protocol that is designed to be energy efficient during identification and monitoring. Extensive simulation studies show ResMon's energy consumption to be significantly lower than state of the art framed Aloha variants; thus, making it ideal for use in RFID-enhanced WSNs.

Statement of Originality

This is to certify that the work described in this thesis is entirely my own, except where due reference is made in the text.

No work in this thesis has been submitted for a degree to any other university or institution.

Signed

Dheeraj K Klair

18th May, 2009

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List of Abbreviations

ABS	Adaptive Binary Splitting
ACK	Acknowledgement
AQT	Adaptive Query Tree
ASC	Allocated Slot Counter
BBT	Bit-by-Bit
BF	Body Frame
BFSA	Basic Framed Slotted Aloha
BFSC	Body Frame Slot Counter
BQ	Bit Query
BS	Binary Search
BTA	Bitwise Arbitration
BTS	Basic Tree Splitting
CDMA	Code Division Multiple Access
CQ	Candidate Queue
CRC	cyclic Redundancy Check
DFSA	Dynamic Framed Slotted Aloha
DoD	Department of Defense
EBBT	Enhanced Bit by Bit Binary Tree
EBS	Enhanced Binary Splitting
EBSA	Enhanced Binary Search Algorithm
EDFSA	Enhanced Dynamic Framed Slotted Aloha
EOF	End-of-Frame
FDMA	Frequency Division Multiple Access

FSA	Framed Slotted Aloha
HQT	Hybrid Query Tree Protocol
ID	Identifier
ID-BTS	ID-Binary Tree Stack
IQT	Improved Query Tree
MAS	Multi-Slotted with Assigned Slots
MBBT	Modified Bit by Bit Binary Tree
MCU	Microcontroller Unit
MEMS	Micro-Electro-Mechanical Systems
MF	Monitor Frame
MS	Multi-Slotted
MSB	Most Significant Bit
MSS	Multi-Slotted with Selective Sleep
NACK	Negative Acknowledgement
PA	Pure Aloha
PC	Personal Computer
PN	Pseudo-Random Sequence
PSC	Progressed Slot Counter
Q	queue
QT	Query Tree
QT-im	Query-Tree Incremental-Matching
QT-sl	Query-Tree Short-Long
QTR	Query Tree Based Reservation
RF	Radio Frequency
RFID	Radio Frequency IDentification
RH-QT	Randomized Hashing Query Tree
RN16	16-bit Random Number
RTF	Reader-Talk-First
SA	Slotted Aloha
SBPP	Scanning Based Pre-Processing
SDMA	Space Division Multiple Access
SO	Slot Offset

SOF	Start-of-Frame
TDMA	Time Division Multiple Access
TS	Tree Splitting
TSA	Tree Slotted Aloha
TTF	Tag-Talk-First
UFSC	Unique Frame Slot Counter
WSN	Wireless Sensor Network