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Tampere University of Technology, Finland

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Preface

Wireless short-range networking bloomed in late 1990s when the first WLAN and Bluetooth standards were completed and the technology migrated to early consumer products. The first standards targeted simple wireless applications like the file transfer between a limited number of devices. Dreams and visions about ubiquitous networking had already started at that time with the concept of thousands of communicating gadgets in our everyday life. It was natural to try the first experiments of ubiquitous networking with the current existing standards, but soon it turned out that the commercial devices were not feasible for such applications. Later on several proposals were presented for wireless sensor networks, but there are still many application domains where a single, or even a couple of standards, can not completely fulfill all the requirements. For this reason many proprietary wireless sensor network (WSN) technologies have emerged.

Soon after the advent of the first WLAN standards much of the research focused on improving and enhancing known deficiencies especially for Quality of Service (QoS) and security. Another branch of research attempted to adapt the standard to fit completely new set of applications not previously intended for the purpose of the original standard. In both cases such gradual developments can improve something but not necessarily make a major scientific breakthrough.

Our approach has been different. We started from scratch, focusing on what we wanted to do with WSNs and then began to search the technology base for what we needed. No WSN standards were available when we started our short-range wireless activities in 1997, only the first visions and ideas about ubiquitous networking. Over the years, we persistently developed our own WSN technology with the help of a large group of talented PhD and MSc students.

Right from the beginning we realized that WSNs introduced a far greater challenge, well exceeding that of mobile phone networks, which were the hot topic of the 1990s. We started with a broad frontier of knowledge from theoretical analysis to full-scale prototype implementations and real-life deployment experiments. Our strength has been the ability to realize the inventions in practical terms, taking into account the real-world non-ideas for the purposes of getting the design to really work. We have also developed new design tools to support the research since none of the existing simulator frameworks were complete enough to meet our wide design scope.

We have experienced how long the road is from taking a new algorithm on a scratchpad to developing a working mesh WSN and would like more realism to be reflected in scientific WSN publications in general. One of the most severe problems is the lack of holistic view. We have learned the hard way in that any real WSN cannot be simplified for a couple of algorithms and considered in a vacuum either. One slight detail can have a drastic effect

on the whole network, multiplying the energy consumption, or driving the whole network in an unstable state. Surprisingly, it is not self-evident what information should be probed from a deployed WSN pertaining to its operation. For that purpose we have developed mechanisms for performing WSN self-diagnostics and automated it with our tool support.

At this point it should be noted that we have focused on WSNs consisting of embedded, resource-limited nodes with small-to-moderate physical size. Such nodes can be used on their own or attached to many kinds of devices or activities. Target lifetime is years of operation, during which large amounts of data is collected. It is also important to note that we have targeted completely autonomous WSNs that do not need any external control. For example, each node computes mesh routing independently, but in collaboration with other nodes and without any central router or network coordinator. This is important to make network deployment very fast without preliminary planning and manual configuration. We think that the best WSN is one that is invisible WSN to users.

We are proud to present this book that details our findings, inventions, and experiments in low-power mesh WSNs. We are confident this volume will provide a fresh outlook to the key design issues and show how they can be approached. This book will also serve as teaching material, although it is not written in the form of a textbook with homework problems.

The research work has been funded by several research projects in collaboration with a number of companies, Tekes (Finnish funding agency for technology and innovations) and Academy of Finland.

Abbreviations

ACK	Acknowledgment
ACL	Access Control List
ACQUIRE	Active Query forwarding In Sensor Networks
ADC	Analog-to-Digital Converter
AES	Advanced Encryption Standard
AJAX	Asynchronous JavaScript and XML
ANSI	American National Standards Institute
API	Application Programming Interface
APS	Application Support
ASIC	Application Specific Integrated Circuit
ATEMU	Atmel Emulator
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
BI	Beacon Interval
B-MAC	Berkeley Media Access Control
BO	Beacon Order
CAN	Controller Area Network
CAP	Contention Access Period
CBC	Cipher Block Chaining
CBR	Constant Bit Rate
CCA	Clear Channel Assessment
CCM	CTR with CBC-MIC

CDMA	Code Division Multiple Access
CFP	Contention-Free Period
CMAC	Cipher-based Message Authentication Code
CORBA	Common Object Request Broker Architecture
COTS	Commercial Off-The-Shelf
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
CSMA	Carrier Sense Multiple Access
CSMA-CA	Carrier Sense Multiple Access with Collision Avoidance
CTR	Counter
CTS	Clear-To-Send
DAC	Digital-to-Analog Converter
DCA	Dynamic Channel Assignment
DCF	Distributed Coordination Function
DD	Directed Diffusion
DECT	Digital Enhanced Cordless Telecommunications
DLL	Data Link Layer
DoS	Denial-of-Service
DSAP	Data Service Access Point
DSL	Digital Subscriber Line
DSR	Dynamic Source Routing
DSSS	Direct Sequence Spread Spectrum
DVM	Distributed Virtual Machine
DVS	Dynamic Voltage Scaling
EAR	Eavesdrop-And-Register
ECB	Electronic Codebook
ECC	Elliptic Curve Cryptography
ED	Energy Detection

EEPROM	Electrically Erasable Programmable Read-Only Memory
EFSM	Extended Finite State Machine
ENDP	Energy-efficient Neighbor Discovery Protocol
ESB	Embedded Sensor Board
FAMA	Floor Acquisition Multiple Access
FAR	Face Aware Routing
FDMA	Frequency Division Multiple Access
FFD	Full Function Device
FHSS	Frequency Hopping Spread Spectrum
FIFO	First-In-First-Out
FPGA	Field Programmable Gate-Array
FSM	Finite State Machine
FTP	File Transfer Protocol
GDI	Great Duck Island
GFSK	Gaussian Frequency Shift Keying
GPRS	General Packet Radio Service
GPS	Global Positioning System
GPSR	Greedy Perimeter Stateless Routing
GRAB	Gradient Broadcast
GSM	Global System for Mobile Communications
GSN	Global Sensor Network
GTS	Guaranteed Time Slot
GUI	Graphical User Interface
GW	Gateway
HAL	Hardware Abstraction Layer
HCI	Host Controller Interface
HIPERLAN/2	High-Performance Radio Local Area Network type 2
HIPERMAN	High-Performance Radio Metropolitan Area Network

HomeRF	Home Radio Frequency
HRMA	Hop Reservation Multiple Access
HTML	Hypertext Markup Language
HTTP	Hypertext Transfer Protocol
HVAC	Heating, Ventilation & Air Conditioning
HW	Hardware
IC	Integrated Circuit
I2C	Inter-Integrated Circuit
ICMP	Internet Control Message Protocol
ID	Identifier
IEEE	Institute of Electrical and Electronics Engineers
I/O	Input/Output
IP	Internet Protocol
IPC	Inter-Process Communication
IR	Infrared
IREQ	Interest Request
ISM	Industrial, Scientific, Medicine
JDBC	Java Database Connectivity
JMS	Java Message Service
JSR	Java Specification Request
JVM	Java Virtual Machine
KDC	Key Distribution Center
L2CAP	Logical Link Control and Adaptation Protocol
LAN	Local Area Network
LEACH	Low-Energy Adaptive Clustering Hierarchy
LED	Light Emitting Diode
LFSR	Linear Feedback Shift Register
LIFS	Long Inter-Frame Spacing

LLC	Logical Link Control
LM	Link Manager
LMP	Link Manager Protocol
LOS	Line-of-Sight
LQI	Link Quality Indication
LR-WPAN	Low-Rate Wireless Personal Area Network
LWA	Linux Wireless sensor network Adaptation
MAC	Medium Access Control
MACA	Multiple Access with Collision Avoidance
MACAW	Media Access protocol for Wireless LANs
MARE	Mobile Agent Runtime Environment
MCU	Micro-Controller Unit
MIC	Message Integrity Code
MiLAN	Middleware Linking Applications and Networks
MIPS	Million Instructions Per Second
MMAC	Multichannel MAC
MMI	Mixed-Mode Interface
MoC	Model of Computation
MOM	Message Oriented Middleware
MOS	Mantis Operating System
MPDU	MAC Protocol Data Unit
MSAP	Management Service Access Point
MSDU	MAC Service Data Unit
MTS	More-to-Send
NAMA	Node Activation Multiple Access
NCAP	Network Capable Application Processor
NoC	Network-on-Chip
NP	Neighbor Protocol

NWK	Network
OMG	Object Management Group
ORB	Object Request Broker
OS	Operating System
OSI	Open Systems Interconnection
PACT	Power Aware Clustered TDMA
PAMAS	Power Aware Multi-Access protocol with Signaling
PAN	Personal Area Network
PC	Personal Computer
PCB	Printed Circuit Board
PDA	Personal Digital Assistant
PDSAP	Physical Data Service Access Point
PDU	Protocol Data Unit
PHY	Physical
PHP	Hypertext Pre-Processor
PID	Process Identifier
PIN	Personal Identification Number
PIO	Parallel Inout/Output
PIR	Passive Infrared
PLL	Phase Locked Loop
PMSAP	Physical Management Service Access Point
POSIX	Portable Operating System Interface
PRNET	Packet Radio Network
PSoC	Programmable System-on-Chip
PWM	Pulse-Width Modulation
QoS	Quality of Service
RADV	Route Advertisement
RF	Radio Frequency

RFD	Reduced Function Device
RFID	Radio Frequency Identification
RPC	Remote Procedure Call
RREQ	Route Request
RSSI	Received Signal Strength Indicator
RTOS	Realtime Operating System
RTS	Request-To-Send
RTT	Round Trip Time
RX	Receive
SAP	Service Access Point
SAR	Sequential Assignment Routing
SD	Superframe Duration
SDL	Specification and Description Language
SDU	Synchronization Data Unit
SEE	Sensor Execution Environment
SEP	Schedule Exchange Protocol
SF	Superframe
SIFS	Short Inter-Frame Spacing
SIG	Special Interest Group
SINA	Sensor Information and Networking Architecture
SKKE	Symmetric-Key Key Exchange
S-MAC	Sensor-MAC
SMACS	Self-Organizing Medium Access Control for Sensor Networks
SMD	Surface Mount Device
SMS	Short Message Service
SNAP	Sensor Network Asynchronous Processor
SNEP	Secure Network Encryption Protocol
SO	Superframe Order

SoC	System-on-Chip
SPI	Serial Peripheral Interface Bus
SPIN	Sensor Protocols for Information via Negotiation
SpeckMAC	Speck Medium Access Control
SpeckMAC-B	Speck Medium Access Control Backoff
SpeckMAC-D	Speck Medium Access Control Data
SQL	Structured Query Language
SQTL	Sensor Querying and Tasking Language
SRAM	Static Random Access Memory
SRSA	Self-Organizing Slot Allocation
SSF	Scalable Simulation Framework
SSL	Secure Sockets Layer
SSP	Security Service Provider
STEM	Sparse Topology and Energy Management
SW	Software
SWAN	Simulator for Wireless Ad-hoc Networks
SYNC	Synchronization
TBF	Trajectory-Based Forwarding
TC	Trust Center
TCB	Thread Control Block
TCL	Tool Command Language
TCP	Transmission Control Protocol
TDMA	Time Division Multiple Access
TDOA	Time Difference of Arrival
TEDD	Trajectory- and Energy-Based Data Dissemination
TEDS	Transducer Electronic Data Sheet
TII	Transducer Independent Interface
TIM	Transducer Interface Module

T-MAC	Timeout-MAC
TML	Token Machine Language
TOSSF	TinyOS Scalable Simulation Framework
TOSSIM	TinyOS Simulator
TRAMA	Traffic-Adaptive Medium Access
TTDD	Two-Tier Data Dissemination
TUTWSN	Tampere University of Technology Wireless Sensor Network
TUTWSNR	TUTWSN Routing Protocol
TX	Transmit
UART	Universal Asynchronous Receiver/Transmitter
UI	User Interface
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
VM	Virtual Machine
WEP	Wired Equivalent Privacy
WG	Work Group
WiseMAC	Wireless Sensor MAC
WISENES	Wireless Sensor Network Simulator
WLAN	Wireless Local Area Network
WMAN	Wireless Metropolitan Area Network
WPAN	Wireless Personal Area Network
WSN	Wireless Sensor Network
WWAN	Wireless Wide Area Network
XML	Extensible Markup Language
ZDO	ZigBee Device Object
Z-MAC	Zebra MAC

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