Assessing a low latency energy efficient Cross-Layer WSAN communication protocol stack

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Agenda

- Introduction
- WSAN
- Application Examples
- WSAN Communication Protocol Stack
- Cross-Layer Paradigm
- WSAN Cross-Layer Framework and Interactions
- Implementation and Simulation
- Some results

Introduction

- WSAN group at UP
- MEng
  - Low level approach
  - Aim: Latency minimization and energy efficiency maximization
  - Cross-Layer paradigm: simple framework and stack-wide interactions
  - Simulation of complete protocol stack

WSANs

- WSANs can be regarded as a fusion of the Mobile Ad-hoc NETworks (MANETs) and Wireless Sensor Networks (WSNs).
- **MANETs** are self-configuring network of mobile nodes connected by wireless links - the union of which forms an arbitrary topology. The nodes are free to move randomly and organize themselves arbitrarily.
- **WSNs** comprise distributed small low-cost sensor nodes that collaboratively send sensed data via short wireless transmissions to a base station. WSNs serve as monitoring or observation networks that solely gather sensed data from the physical environment they are deployed in.

WSAN Requirements and Challenges

- Real-time requirement
- Network lifetime and energy efficiency
- Reliability
- **Node heterogeneity**. New challenges are posed by the coexistence of two different types of nodes.

WSAN Requirements and Challenges (2)

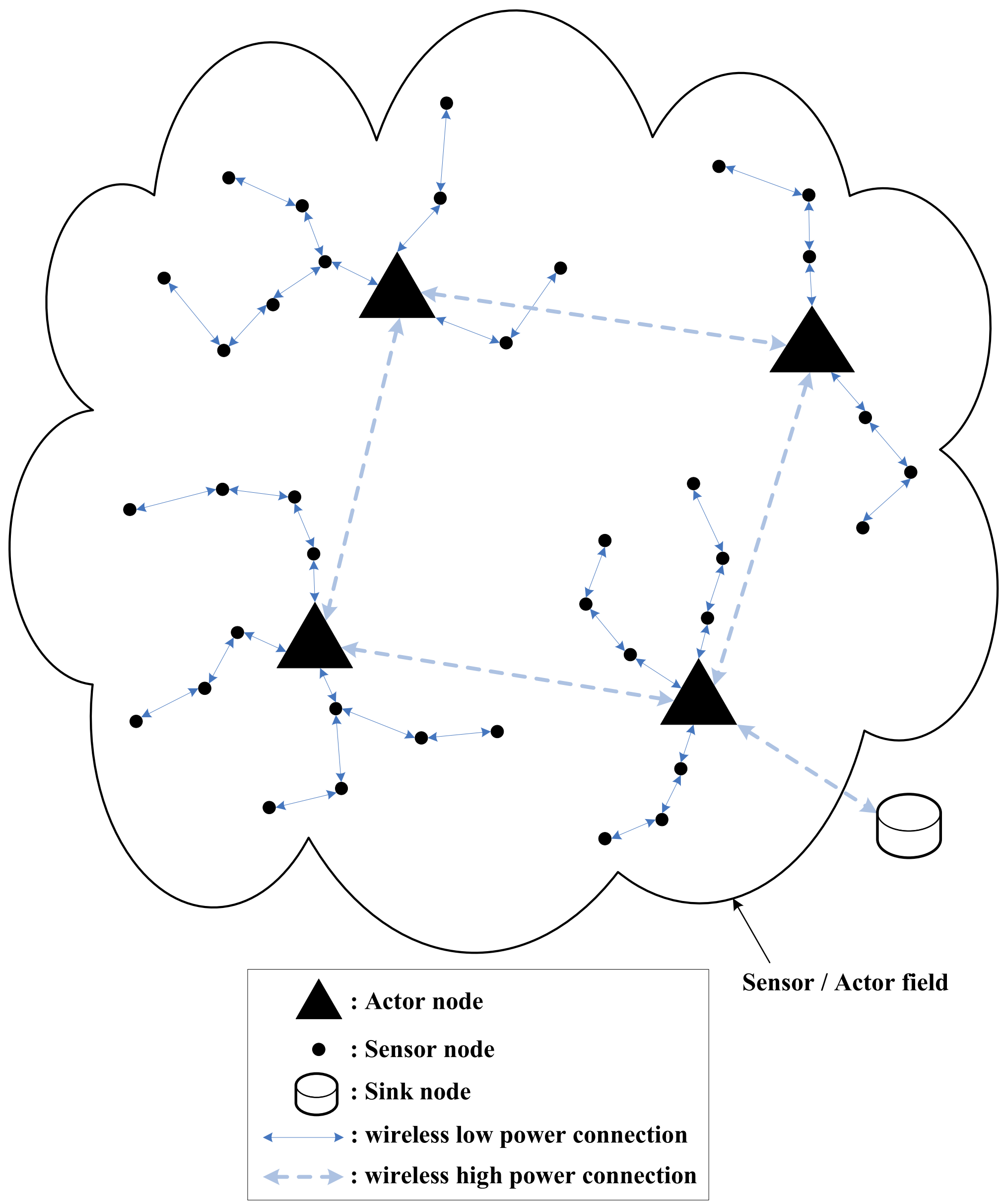
- **Hardware Constraints**. High volumetric node density → production cost must be kept to minimum. Therefore, sensor nodes have limited *processing capabilities*, a small amount of *memory*, a *short range transceiver* and a ***very limited energy source.***

- **Mobility**. Some applications require WSANs to cater for the possibility of mobile actor nodes.

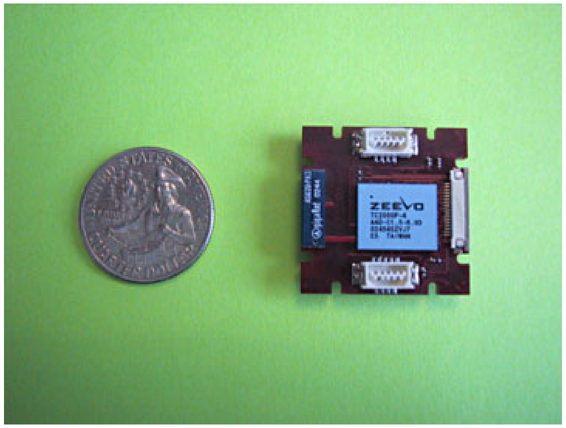
- **Topology**. The network topology of WSANs may change from time to time as new sensor nodes are added or energy depleted nodes 'die'.

- **Scalability.**

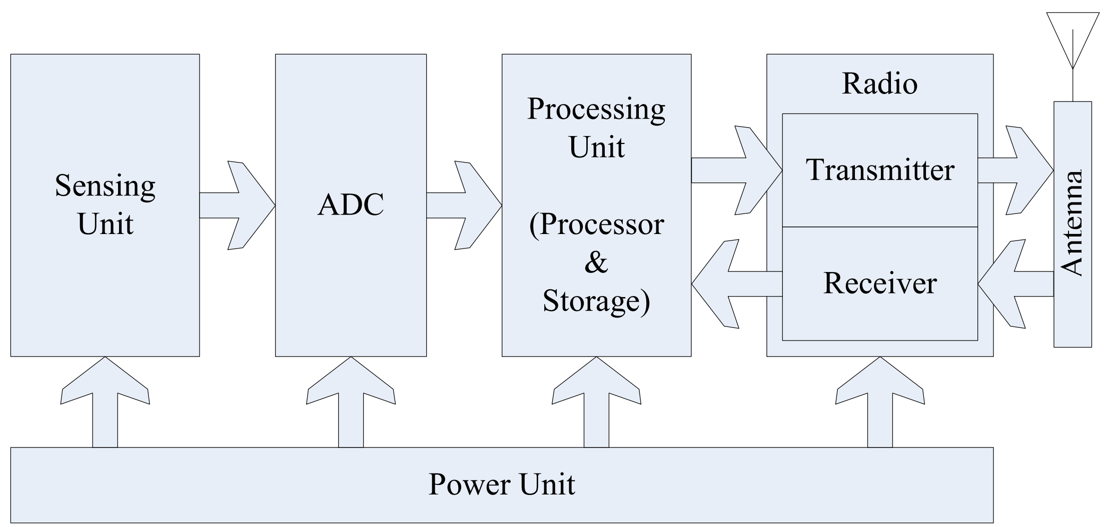
Physical Architecture



Sensor nodes: MICA2 and Intel Mote



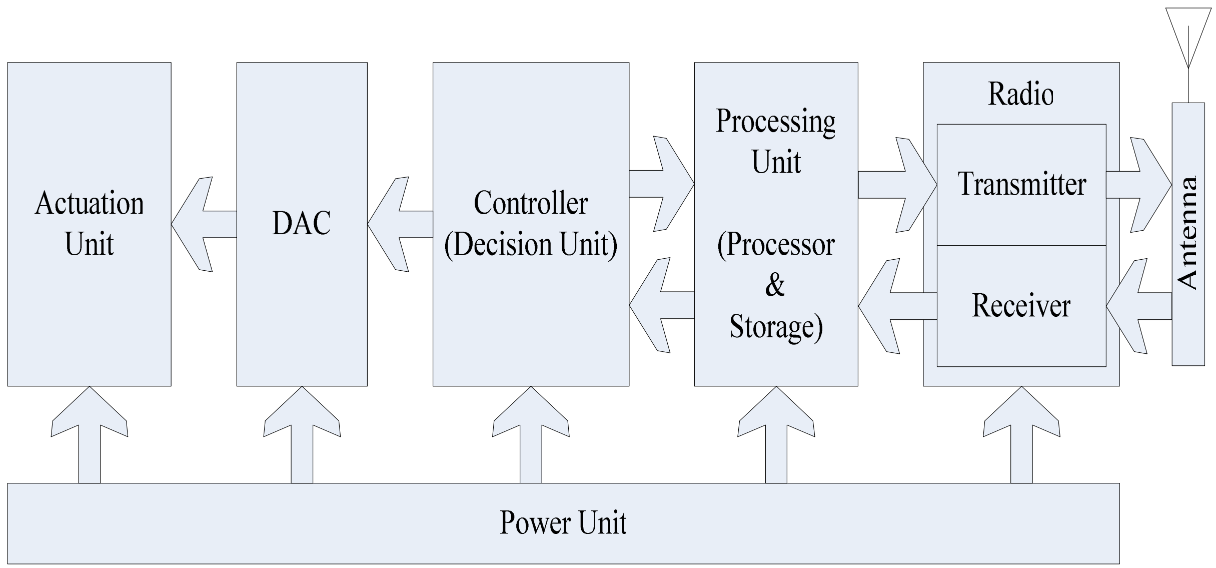
Sensor Node Architecture



Sensor node radio

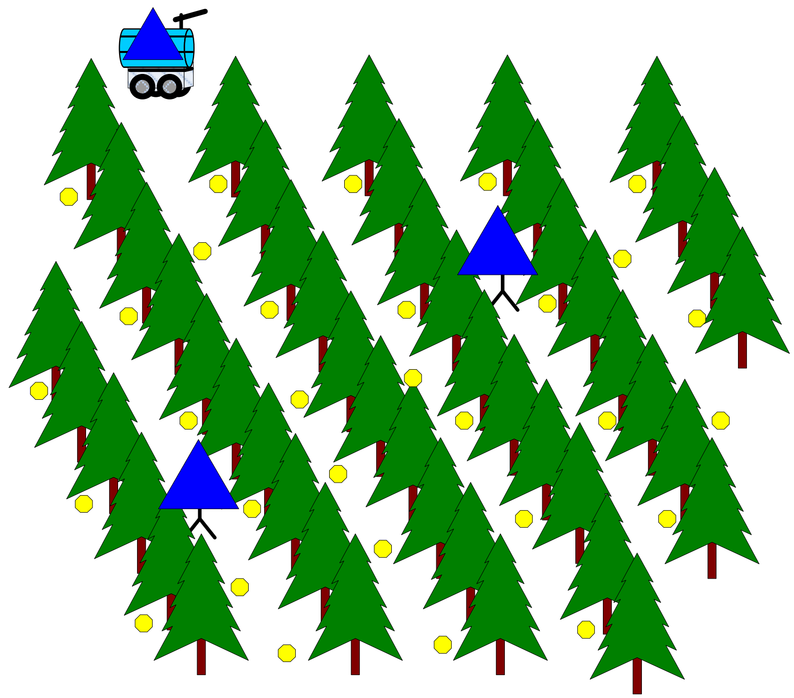
- Radio frequency (RF) transmissions
- Uses of the industrial, scientific and medical (ISM) bands
- Small-sized, low-cost and ultra low power transceiver
- Antenna efficiency and power consumption limit the choice of a carrier frequency for such transceivers to the ultrahigh frequency range. Popular radios make use of bands at 433 MHz, 868 MHz, 915 MHz and 2.4 GHz.
- Transmitting at higher frequency bands requires more power for the same distance but allows higher bandwidth. The higher bandwidth permits shorter transmitting time and smaller antennas.
- Bit rates of 10 kbps, 250 kbps or 1 Mbps.

Actor Nodes Architecture



Application Examples

- ***Fire control***: The damage incurred by a fire outbreak depends mostly on the time it took to respond to the outbreak. A timely response to fire outbreaks is the most crucial requirement of fire control.

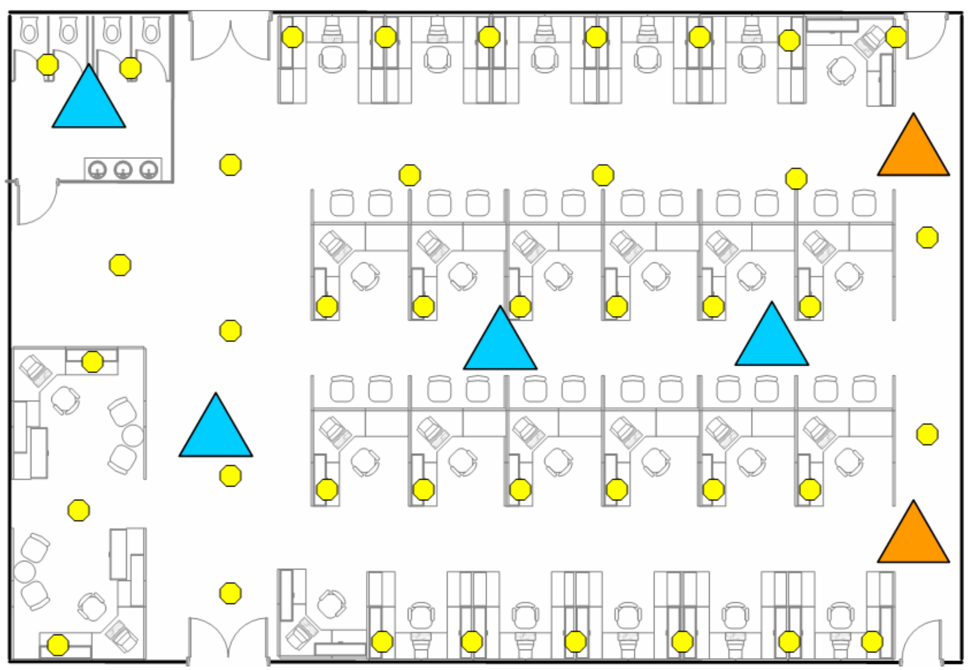


Application Examples (2)

- **Target tracking and attack detection**: Sensor nodes are distributed on a battlefield to sense movement and sound for example. They relay monitoring and critical event information to robots.

Application Examples (3)

- ***Microclimate and lighting control in buildings***: Modern buildings feature highly sophisticated heating, ventilation and air conditioning systems that require extensive monitoring and control over the specific settings.



Application Examples (4)

- ***Home automation**:* A modern home contains a large number of appliances and equipment that can be both remotely monitored and controlled.

- ***Planet exploration**:* The WSAN can be applied to aerospace industries as well. For example, a number of sensor nodes and actuator nodes can be deployed on a planet for exploration.

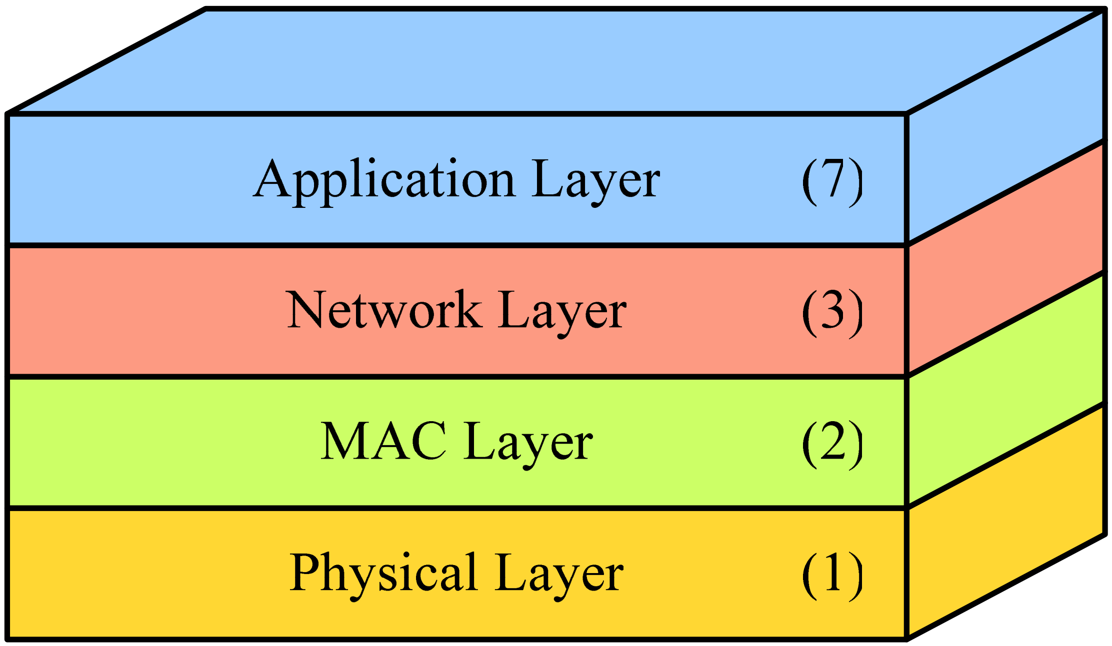
- ***Structural damage detection**:* Systems that detect and locate damage in large structures such as buildings, ships, bridges and aircraft can improve safety and reduce maintenance costs.

- ***Precision farming***: In the quest to make agricultural processes more automated and efficient, WSANs concentrate on providing the means for observing, assessing and controlling agricultural practices. (very relevant for SA)

Common basic operational scenario

1. Sensing
2. Evaluating
3. Sending to actor node
4. Actor node responding

WSAN Communication Protocol Stack



WSAN research

- Very little protocol research has been done specifically for WSANs
- The WSN is the most comparable type of network
- In WSN protocol domain, **energy efficiency** is the main requirement

WSAN Application Layer

- Senses physical environment periodically
- Evaluates sensed value
- Sets data packet type

WSAN Network Layer

- Cluster formation around actor nodes
- Maintains table with information of neighbour nodes
- Chooses route according to cost metric
  - Remaining energy
  - Traffic load

WSAN MAC Layer

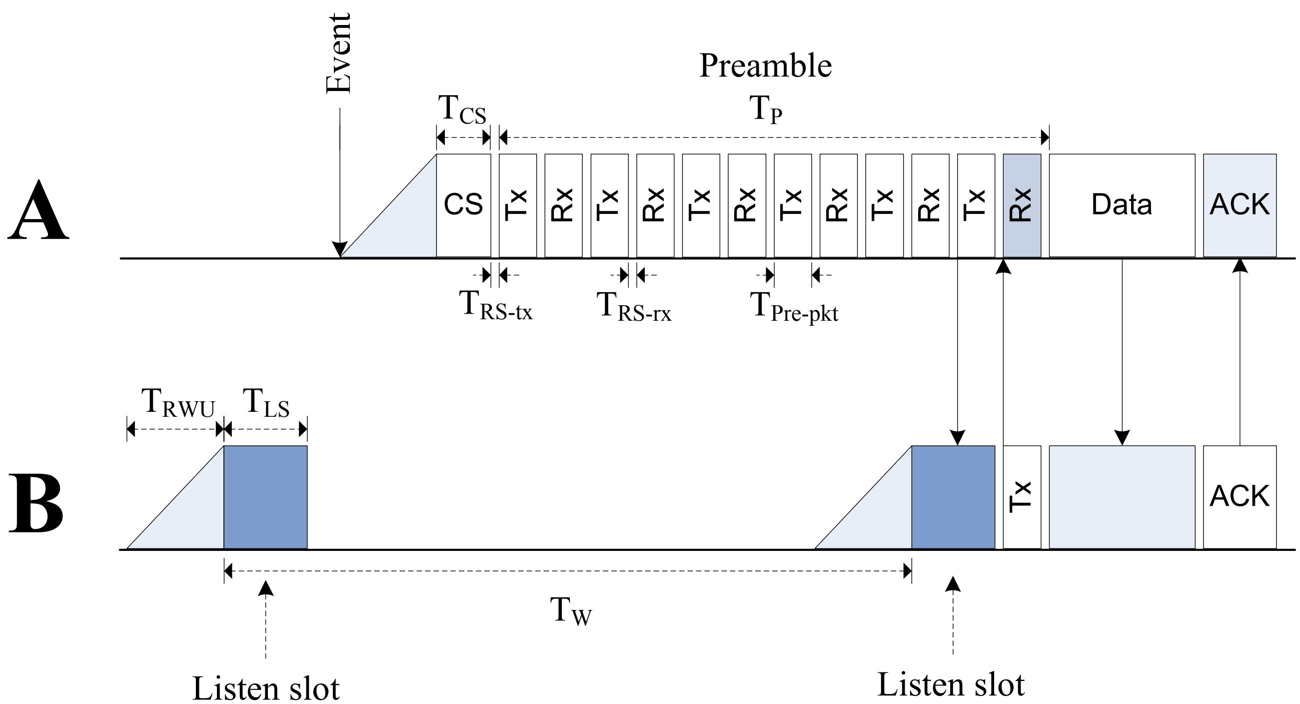
- Contention based CSMA-Minimum Preamble Sampling protocol
- Maintains wakeup schedules of direct neighbour nodes

Main advantages of contention-based approach:

- Lower delays
- Only loose synchronization needed
- Scalable
- Easy handling of topology changes
- Simple design
- Can be combined with scheduling to promote energy efficiency
- Low duty cycles can save a lot of energy
- Easy and dynamic changing of individual node duty cycles and listen interval

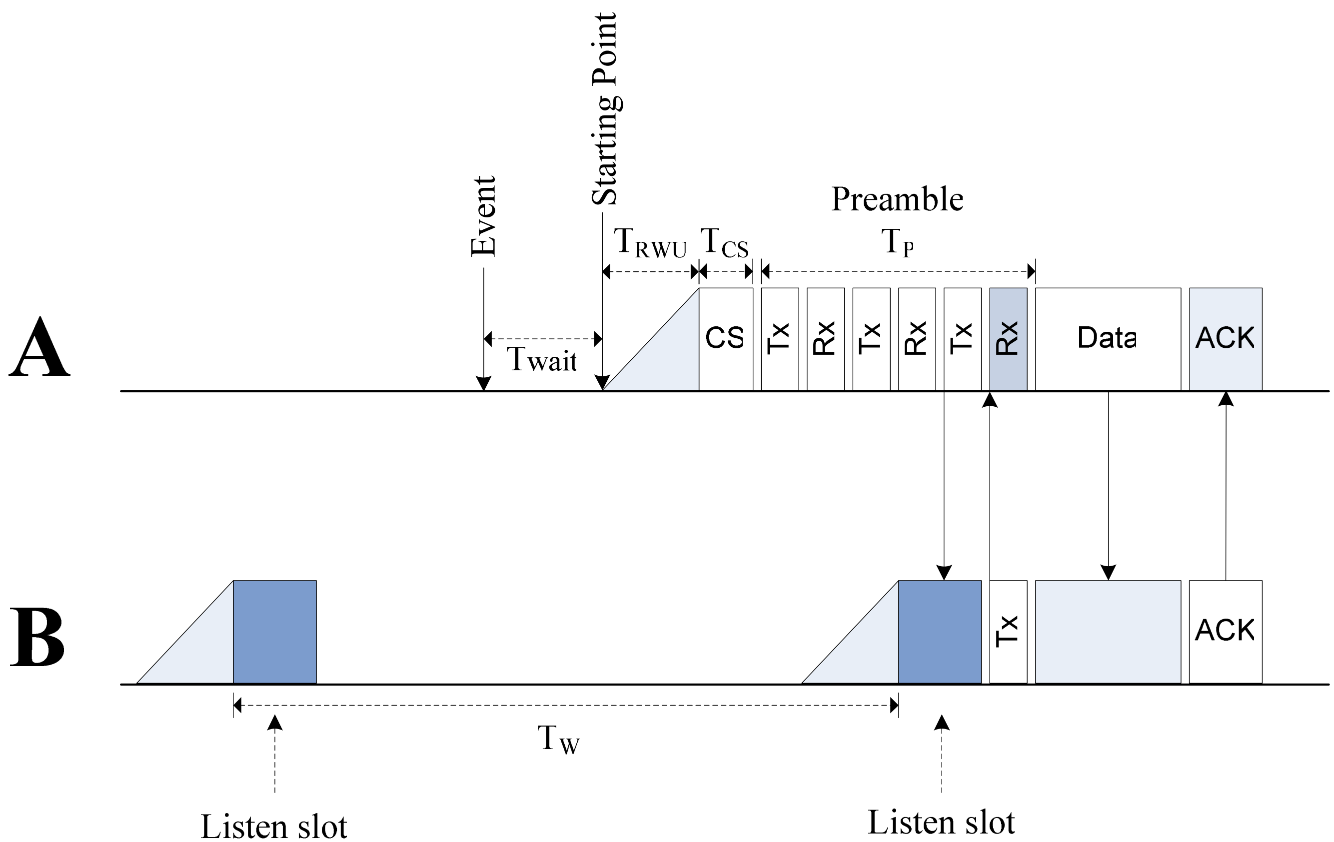
WSAN MAC Layer (2)

- Unsynchronized mode



WSAN MAC Layer (3)

- Synchronized mode



WSAN Physical Layer

- Radio is the primary energy consumer → important to choose suitable transceiver for energy constrained sensor nodes
- Radio states: transmit, receive, idle or sleep
- The less time the radio is busy with transmitting, receiving and idling, the longer the sensor node's lifetime.
- The main control of the radio is done by the MAC layer, which issues sleep and wakeup commands.

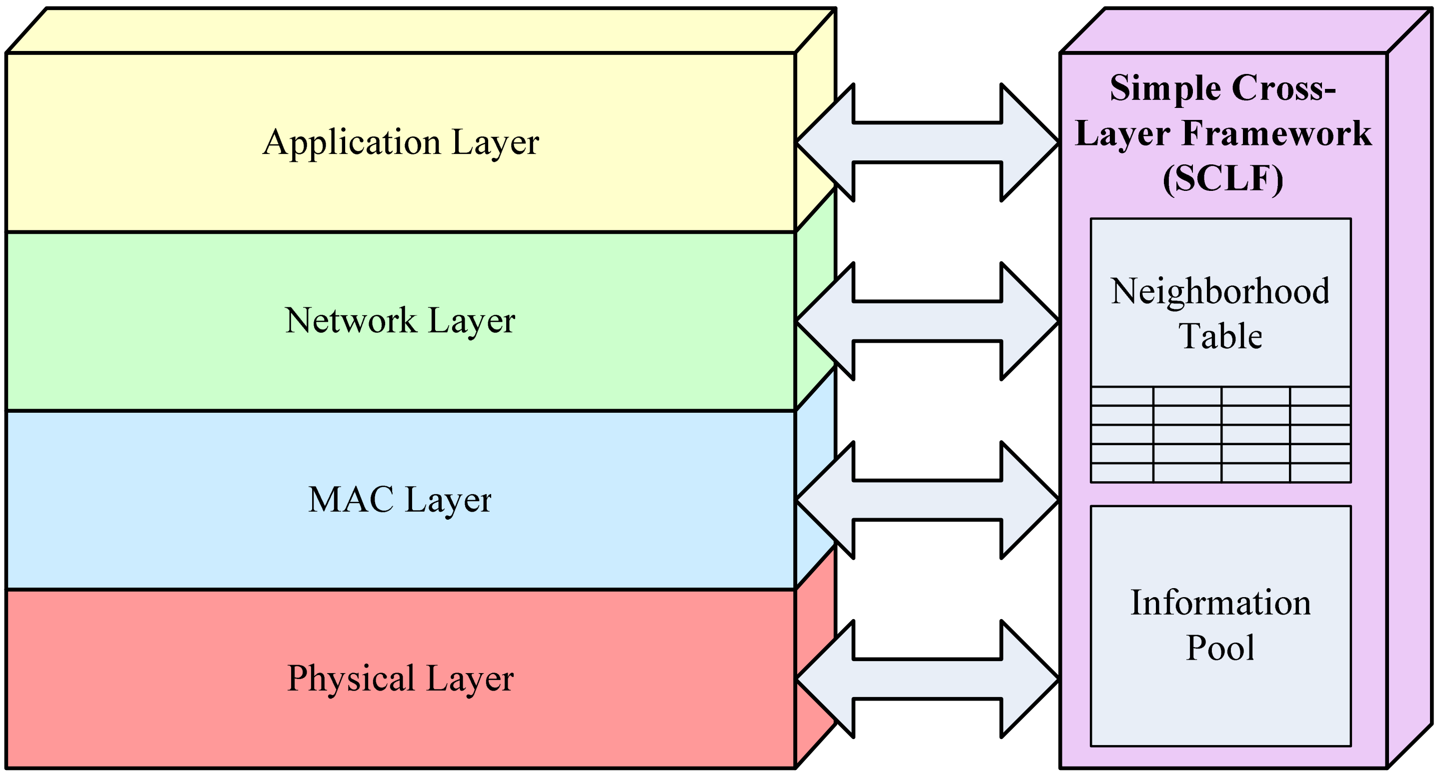
The Cross-Layer Paradigm

- Recently attracted increasing attention of researchers and communication system designers.
- The wave of attention stems from the large and active community dealing with challenging networking environments such as mobile ad hoc networks, next-generation cellular networks, or sensor networks.
- Involves layer interaction and communication
- Promises high performance gains

Cross-Layer framework design for WSANs

- simple and generic design
- easily accessibility of information
- little overhead incurring
- low memory usage

WSAN Cross-Layer framework



Information Pool Entries

	Parameter/Feature	Description
Application Layer	State information	The state information indicates the current state of the APPL protocol.
	T_{Per}	The period a node waits between requesting a value from the sensing unit, i.e. takes a measurement.
	Packet type	This parameter is contained in the APPL packet header and can be read by the lower layers. The packet type specifies packets containing a sensed value below the critical threshold as *non-critical* and above the threshold as *critical*.
Network Layer	Status information	The status indicates if the node can be regarded as connected or not connected to the rest of the network.
	Neighbourhood table	The information of neighbour nodes within transmission range. Includes the address, hop distance to its actor node, traffic load, remaining energy E_R and a timestamp.
	Traffic load	The amount of packets received and sent by the NETL during a specific period.
	Hop distance	The hop distance from a node to its assigned actor node.
	Packet type	This parameter is contained in the NETL packet header and can be read by the lower layers. The packet type specifies if the packet is a NETL metric update packet or an APPL data packet.
MAC Layer	Neighbourhood table	The information of neighbour nodes within transmission range. Includes the neighbours' wakeup time, the wakeup interval, the channel condition, the time of last successful communication and a reachable flag
	Channel condition	The amount of CS failures recorded over a specific time period.
	Queue information	The MAC queue size and length.

Neighbourhood Table Entries

	Neighbour Info	Description
Network layer info	Neighbour address	The address of the node.
	Hop distance	The hop distance from the node to its actor node.
	Remaining energy	The remaining battery energy level.
	Traffic load	The latest traffic load value.
MAC layer info	Wakeup Time	The time to the next wakeup.
	Wakeup Interval	The period between wakeups.
	Channel condition	The latest recorded CS failure rate.
	Last successful communication timestamp	The time of the last successful communication with received ACK.
	Reachable flag	An indication that the last communication attempt was successfully completed.
	Timestamp	The time of last updated entry.

Information used by the Application Layer

NETL	Network Layer Status
	Traffic Load
	Hop distance from actor node
MACL	Queue size and current length
	Carrier sense failure rate

- Data Aggregation (hop distance, CS)
- Sensing period adjusting (traffic load, CS)

Information used by the Network Layer

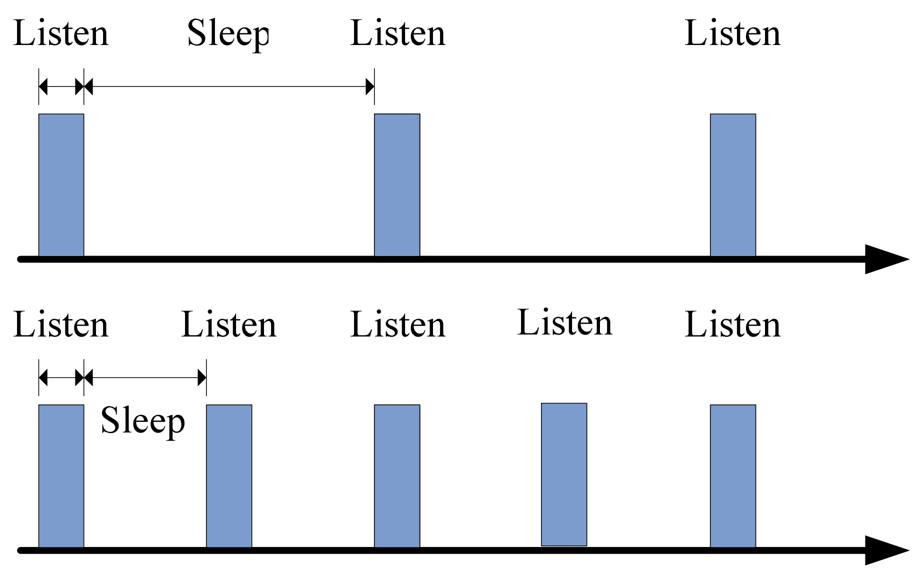
APPL	Sensed packet type
	Sensing period T_{per}
MACL	Neighbourhood table- wakeup time
	Neighbourhood table- wakeup interval
	Neighbourhood table- channel condition
	Neighbourhood table- reachable flag
	Channel condition
	Queue size and current length

- Critical vs. Non-critical data
- Cost metric enhanced by considering
  - MAC timing
  - MAC Channel Condition
- Periodic update sending considers MAC CC

Information used by the MAC Layer

APPL	State	
	Sensed packet type	
NETL	Traffic Load	
	Packet type	

- Listen interval doubling

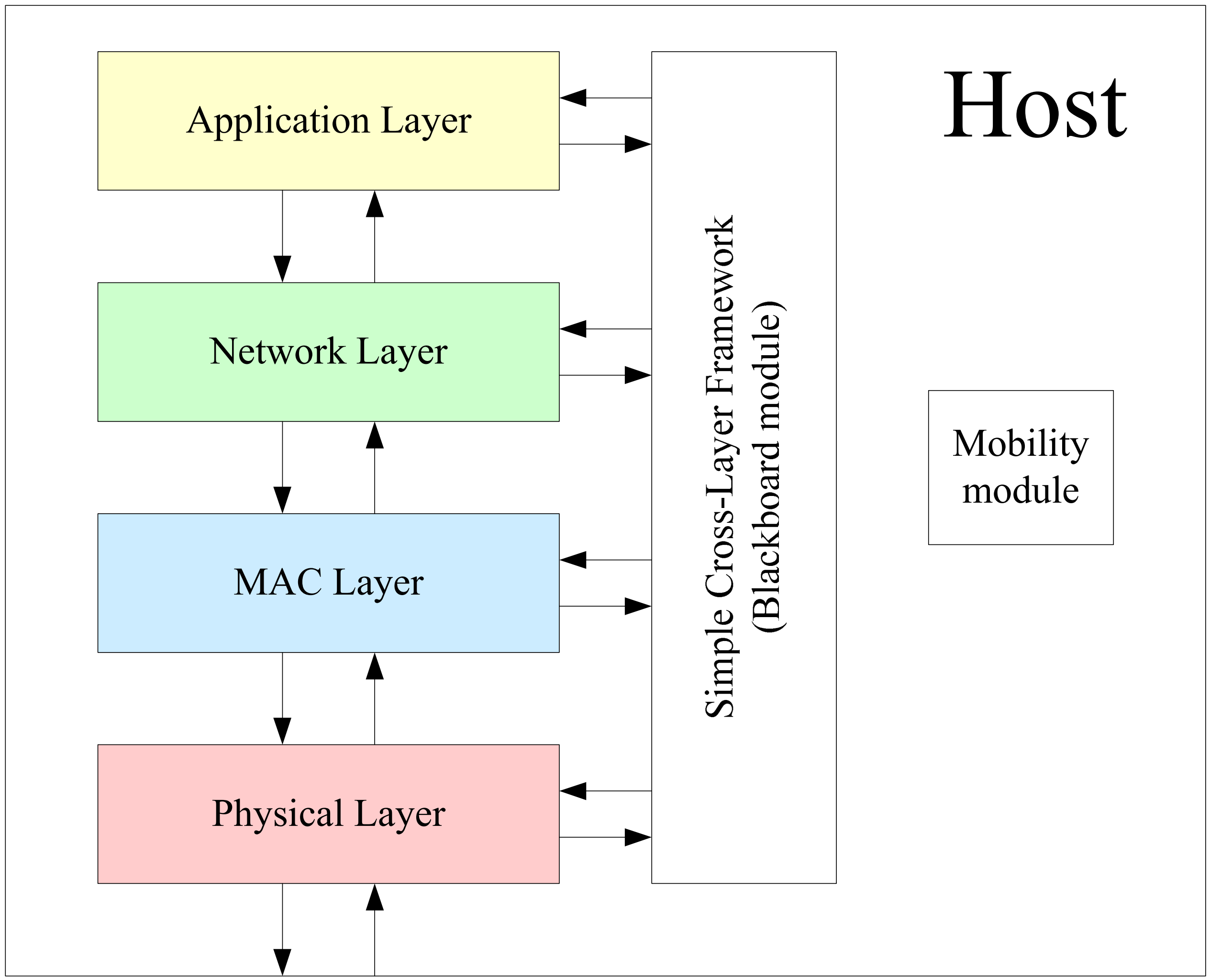


- New Mac queue rules for different packet types

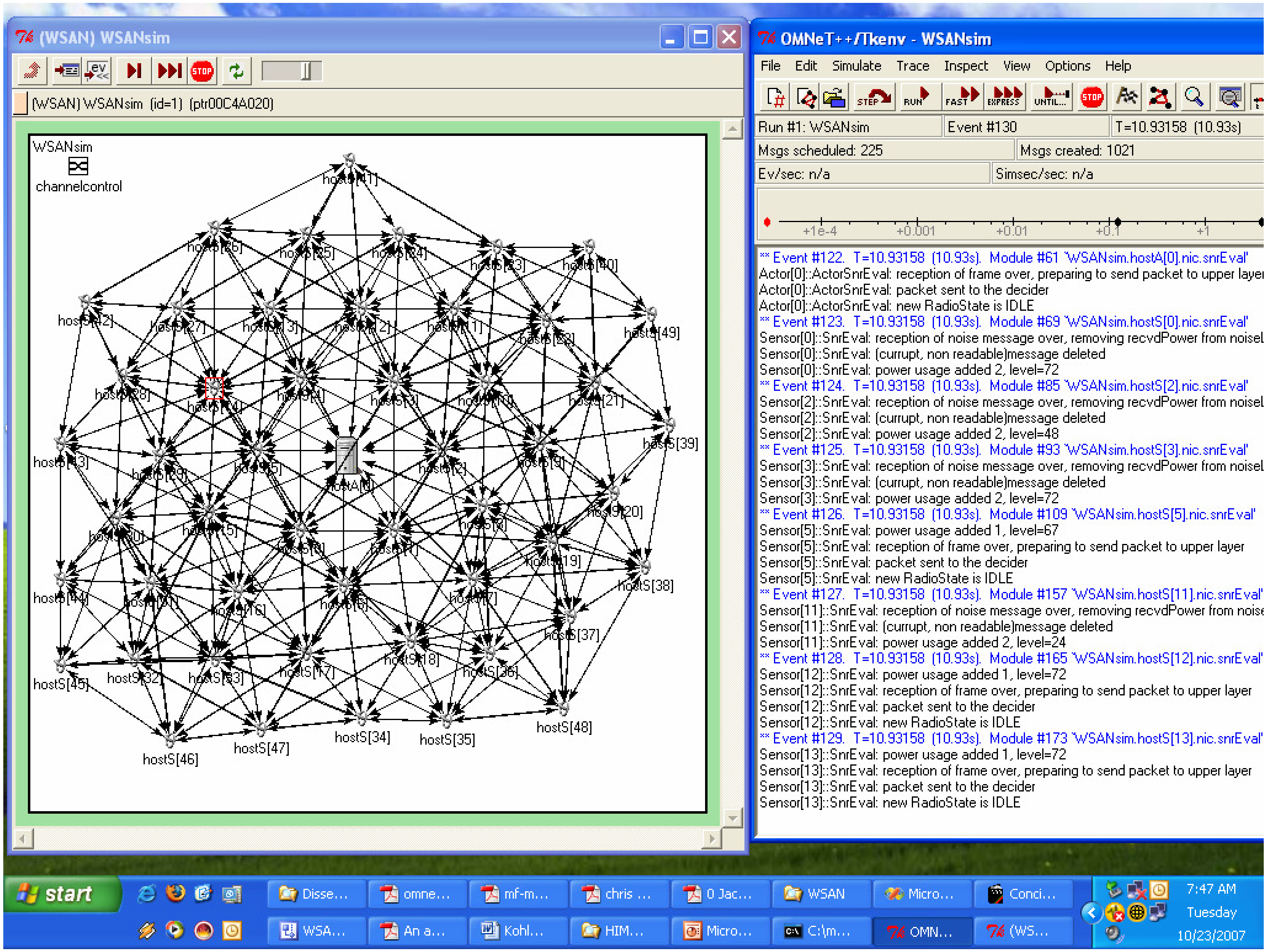
Simulation

- OMNeT++
  - Object-oriented modular discrete event network simulator
  - freely available
  - boasts several frameworks developed for easy implementation and simulation of networks similar to WSANs

Mobility Framework



Simulator Screenshot



- Some initial simulation results have shown up to 30% decrease in latency without listen interval doubling
- and up to 45% decrease in latency with interval doubling

- Further simulations are still be to conducted to determine impact on total and average energy consumptions…