Management of Ubiquitous Sensor Network

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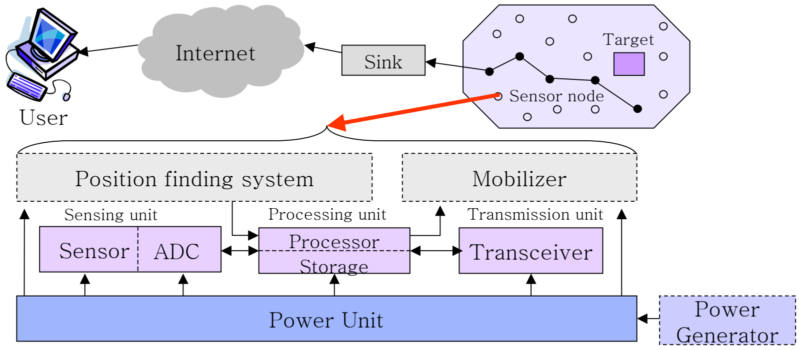
Outline

- **Ubiquitous Sensor Network Technology**
  - Definition of Ubiquitous Sensor Network
  - USN Protocol Stack
  - Current Standardization Activities
    - IEEE 1451, IEEE 802.15.4, ZigBee and 6LoWPAN
  - Location and Synchronization Technology in Sensor Network
- **USN Management Requirements**
- **USN Management Architecture & Functions**
  - USN Management Architecture
  - USN Management Functional Areas
  - Related Research on USN Management Architecture
- **Specific USN Management Functions**
  - Power Management
  - Topology Management
  - Security Management
  - Context Management
- **Conclusion**

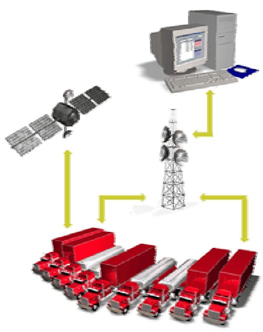
What is Ubiquitous Sensor Network?

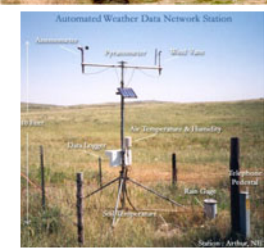
- **Infrastructure network for realizing ubiquitous computing environment using may sensor nodes with sensing, processing & wireless communication capabilities**
- **Cheap and smart sensor node deployed, and monitoring and controlling target environment**



Sensor Network Applications

- **Military**
- **Infrastructure security**
- **Environment & Habitat Monitoring**
- **Industrial Sensing**
- **Traffic Control**
- **Seismic Studies**
- **Life Sciences**





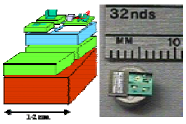
Characteristics of USN

- **Large number of sensor nodes**
  - Maybe 10 to 100,000 nodes (scalability)
  - Node position may not be predetermined
  - Low cost
- **Low energy consumption**
  - To relocate & recharge large number of nodes is impossible
  - Life time of sensor network depends on battery life time
- **Network self-organization**
  - Large number of nodes in hostile locations-> manual configuration unfeasible
  - Nodes may fail & new nodes join the network
  - Ad-hoc sensor network protocols
- **Collaborative/Distributed processing**
  - Locally carry out simple computation -> forwards and aggregate data
- **Query ability (Sensor Database)**
  - Single node or group of nodes
  - Base nodes collect data from given area & create summary messages

USN and Ad-Hoc Network Comparison

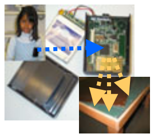
Items for Comparison	Sensor Network	Ad-hoc Network
Number of Nodes	100 ~ 1000	10 ~ 100
Deployment	Densely	Relatively sparsely
Failure	Prone to Failure	Not Prone to Failure
Communication	broadcast	Point-to-point
Topology Change	Very frequent	Almost steady
Power	Limited	Rechargeable
Resource	Limited	Relatively high
ID	Local ID	Global ID(IP Address)

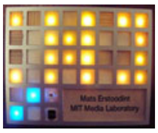
USN Projects



SMART DUST – UC Berkeley
- Autonomous Node 1mm³, MEMS Tech.
- Optical Comm. Module, CCR
- Sensing, Processing, Communication
- Small Size, Low Power, Low Cost

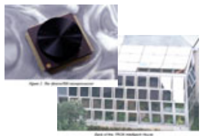
Smart Kindergarten – NESL-UCLA
- iBadge, Childhood education environment
- Monitoring & Analysis
  Evaluations of students progress
  "How well is student A reading the story book B?"



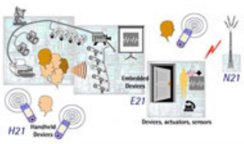


Things The Think (TTT) - MIT Media Lab.
- Embedding computation into everyday things. (such as clothing, jewelry, and tables.)
- Large amount of Project.
  (Wearable Health, Smart City, UbER-Badge etc.)

TRON (The Real-time OS Nucleus) - Japan
- ITRON(Industry TRON), BTRON(Business TRON)
- T-Engine (2002. 6)
  - Tron based Development platform
  - 400 corporations (2004) : MS, Samsung

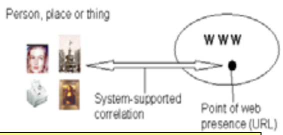


USN Projects (cont')



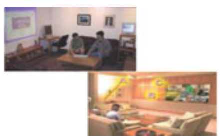
Oxygen – MIT Computer Science Lab
- Computing service available like Oxygen
- Computing access using human centered interface such as natural language and vision

CoolTown – HP
- Real World Wide Web
- Person, place or thing existing on the Web space, communicating each other
- Education, Medicare, ITS, Fire and Safety Service



SMART TAG – MIT Auto-ID Center
- RFID, Supply Chain Management
- Collaboration with EPC Global
- EPC Code, ONS, PML
- Low Cost TAG (Cost < 5 Cent)

Easy Living Project – Microsoft
- Intelligent Environment
- Info. Gathering
  Tradition I/O Device – Mouse, Keyboard, MIC
  Sensing Device – Cameras, Active Badge



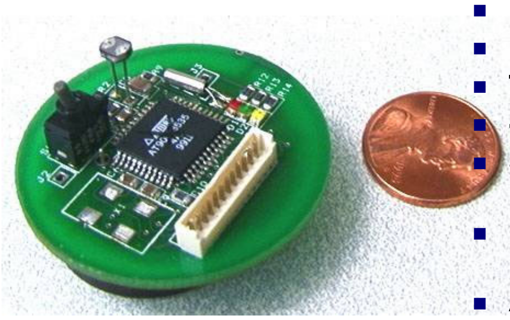
USN Projects (cont')

Smart-Its Project – ETH, TecO, VTT
- Disappearing Computer Initiative (16Projects)
- Development Device
  (Disappearing Computer Initiative)
- Smart Cup (Temp. & User Detecting)

U-Network – Ministry of Internal Affairs & Communications
- Net. Roaming Based On Small Chip & Terminal
- Anywhere Connection
- Hotspot Net. Service → Mobile Network Service
- Project: TRON(Tokyo UNIV.) eHII(Matsushita)

u-Korea – Ministry of Information and Communication
- Development of Key Technologies in Wireless Personal Area Network, UWB (~hundred Mbps), Electronic Tag (RFIC), Intelligent Wireless Sensor Network
- Ubiquitous Home Network and Commodity Circulation Network

Sensor Node Hardware



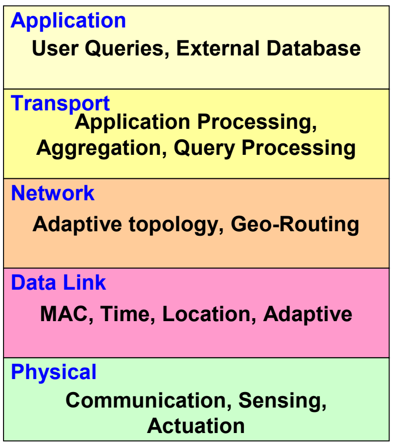
Berkeley Motes-weC Mini Mote

- 19.1 Kbps
- 20m Range
- Light Sensing
- Temperature Sensing
- 4 MHz – 3.0 V
- 8 Kbytes –Program Memory
- 512 Bytes – Data Memory
- Available from: CrossBow Inc. $900 for a complete kit

USN Protocol Stack

Logical Function of Layers

- **Coordinating to minimize duty cycle and communication**
  - Adaptive Topology
  - Routing
  - Adaptive MAC
- **In-network processing**
  - Data centric routing
  - Programming models



Physical Layer

- **Needs**
  - Simple, but robust modulation, transmission, and receiving technique
- **Transmission media**
  - Radio
    - ISM (Industrial, Scientific, Medical) 915MHz band widely suggested
  - Infrared
  - Optical media
- **Open research issue**
  - Modulation scheme
    - Needed simple and low-power modulation scheme
  - Hardware design
    - Tiny, low-power, low-cost
    - Power efficient hardware management strategy

Data Link Layer

- **Responsible for multiplexing of data streams, Medium Access control (MAC) and Error Control**
- **Medium Access Control (MAC)**
  - Creation of the network infrastructure
  - Fairly and efficiently communication resources sharing between sensor nodes
- **MAC for Sensor Network**
  - SMACS (Self-Organizing Medium Access Control for Sensor Networks)
  - EAR (Eaves-drop-And-Register) Algorithm
  - CSMA-Based MAC scheme
  - Hybrid TDMA/FDMA-Based MAC scheme
- **Power Saving Modes of Operation**
- **Error Control**
  - FEC (Forward Error Correction)
  - ARQ (Automatic Repeat Request)

Network Layer

- **Needs**
  - Data Routing
- **Requirement**
  - Power efficiency
  - Data-centric
  - Data aggregation
    - Implosion
    - Overlap

Scheme	Description
Flooding	Broadcasts data to all neighbor nodes
Gossiping	Sends data to one randomly selected neighbor
LEACH	Forms a clusters to minimize energy loss
SPIN	Sends data to sensor nodes only if they are "interested", has 3 types of messages (ADV, REQ, DATA)
Directed Diffusion	Sets up gradients for data to flow from source to sink during interest dissemination
Power Efficiency Routing	Pick a route based on: max Power Available (PA) or, min Energy (ME), or Min Hop (MH) or Max Min PA
Smecn	Creates a sub-graph of the sensor network that contains the minimum energy path
SAR	Creates multiple trees where the root of each tree is one hop neighbor from the sink

Transport Layer

- **Needs**
  - Maintain the flow of data if the sensor networks applications requires it
- **Research**
  - Communication between user and sink node
    - TCP or UDP via the internet or satellite
  - Communication between sink node and sensor node
    - UDP type protocol, because sensor node has limited memory
- **Naming**
  - Not based on global addressing
  - Attribute-based naming

Application Layer

- **Needs**
  - Depending on the sensing tasks, different types of application software built and used
- **Application layer protocols**
  - SMP (Sensor Management Protocol)
    - System administrators interact with sensor networks using SMP
    - Provides the software operations needed to perform the following administrative tasks
  - TADAP (Task Assignment and Data Advertisement Protocol)
  - SQDDP (Sensor Query and Data Dissemination Protocol)

Standardization Activity

IEEE 1451
IEEE 802.15.4
ZigBee
6LoWPAN

IEEE 1451

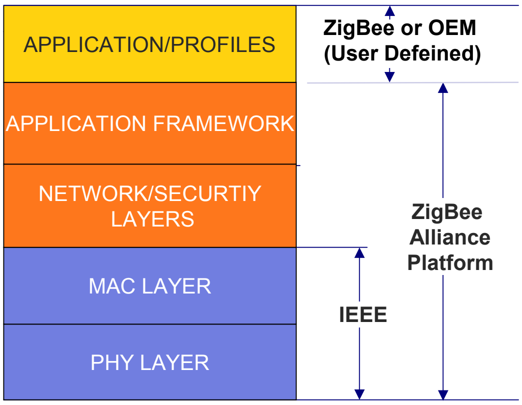
- **A new family of standards for connecting smart transducers to networks**
  - IEEE 1451.1 Network Capable Application Processor (NCAP) Information model for smart transducers
  - IEEE 1451.2 Transducer to Microprocessor Communication Protocols and Transducer Electronic Data Sheet (TEDS) formats
  - IEEE1451.3 Digital Communication and Transducer Electronics Data Sheet (TEDS) Formats for Distributed Multidrop Systems
  - IEEE 1451.4 Mixed-mode Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats

IEEE 802.15.4

- **Key Feature**
  - Data rates o 250kbps, 40kbps, and 20kbps
  - Two addressing modes, 16-bit short and 64-bit IEEE addressing
  - Support for critical latency devices, such as joysticks
  - MAC : CSMA/CA channel access
  - Multi-level security
  - Automatic network establishment by the coordinator
  - Fully handshaked protocol for transfer reliability
  - Power management to ensure low power consumption
- **3 bands, 27 channels**
  - 2.4GHz : 16 channels
  - 868.3 MHz : 1 channel
  - 902~928MHz : 10 channels
- **Issues**
  - Long battery life
  - selectable latency for controllers, sensors, remote monitoring and portable electronics

ZigBee Protocol Stack

- ZigBee takes full advantage of a powerful physical radio specified by IEEE 802.15.4
- ZigBee adds logical network, security and application software



ZigBee Characteristics

- **Addressing**
  Assign the address to node depend on network configuration
- **Location**
  Have a location information depend on a network topology in sensor network
- **Synchronization**
  Common Sync. Technology is used (NTP, RBS, TPSN, FTSP)

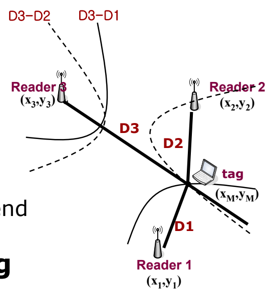
6LoWPAN

- **No method exists to make IP run over IEEE 802.15.4 networks**
  - **Worst case .15.4 PDU 81 octets, IPv6 MTU requirements 1280 octets**
- **Stacking IP and above layers "as is" may not fit within one 802.15.4 frame**
  - **IPv6 40 octets, TCP 20 octets, UDP 8 octets + other layers (security, routing, etc) leaving few bytes for data**
- **Not all adhoc routing protocols may be immediately suitable for LoWPAN**
  - **DSR may not fit within a packet, AODV needs more memory, etc**
- **Current service discovery methods "bulky" for LoWPAN**
  - **Primarily XML based that needs computing, more memory, etc**
- **Limited configuration and management necessary**
- **Security for multi-hop needs to be considered**

Location and Synchronization Technology in Sensor Network

Location Technology in Sensor Network

- **Discovery of absolute or relative location**
  - Geographical routing (location attribute based naming and addressing)
  - Tracking of moving objects
  - Context (location) aware applications
- **Challenges in Sensor Networks**
  - Energy constraint
  - Harsh environment with multipaths
  - Minimal infrastructure (Few beacons, No backend computation)
- **Many techniques for location sensing**
  - TDOA (Time Difference Of Arrival)
  - TOA (Time Of Arrival)
  - AOA (Angle Of Arrival)
  - SSR (Signal Strength Ranging)
  - GPS, etc.



TDOA Locating Algorithm

Time Synchronization in Sensor Network

- **Critical at many layers of sensor network**
  - Communication, localization, distributed DSP, etc.
  - Conventional approaches
    - GPS
      - Indoors?, cost, size, energy
    - NTP (Network Time Protocol)
      - Delay and jitters due to MAC and store-and-forward relaying
      - Discovery of timer servers (nodes synchronize with one of a pre-specified list of time servers)
- **Reference-broadcast synchronization (RBS)**
  - Very high precision sync with slow radios
    - Beacons are transmitted, using physical-layer broadcast, to a set of receivers
    - Time synchronization is based on the difference between reception times, do not sync sender with receivers

USN Management Requirements

Ubiquitous Sensor Network Management

- **Why isn't SNMP (Simple Network Management Protocol) adaptable to USN?**
  - Sensor-specific failures are not handled
  - Difficult to find the failed nodes
  - Physical connections are not utilized
  - Commonly, there is not a management agent
  - Specifying nodes is difficult
  - Network is self-configured, so that management server doesn't have all information of sensor nodes

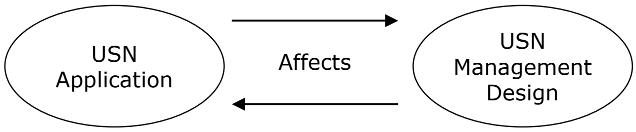
- **Challenges**
  - Presents many and drastically different challenges. For example:
    - Deployment of nodes, Discarding of nodes
  - Requires augmentation to (or new approaches over) traditional network and service management techniques
  - Needs to take into account specific characteristics of WSNs (e.g., energy waste)

USN Management Requirements

- **Fault tolerance**
  - **Handle loss of nodes** - Lack of Power, Physical damage, Environmental interference
- **Scalability**
  - **Handle high density of nodes** - The number of sensor nodes is an extreme value of millions
- **Production costs**
  - **Make them low cost** - Cost of a single node is very important to justify the overall cost of the network
- **Operating environment**
  - **Survive and maintain communication** - The bottom of an ocean, biologically contaminated field, battlefield
- **Transmission media**
  - **Wireless** - Radio, infrared, optical media
- **Hardware constraints**
  - **Nodes are tiny** - Very small size, very light node, limited memory, limited battery
- **Power consumption**
  - **Limited Tx, computation, lifetime** - Replenishment of power is impossible
- **Changing Topology**
  - **Nodes** - Nodes moving, new nodes, loss nodes

USN Management Goal

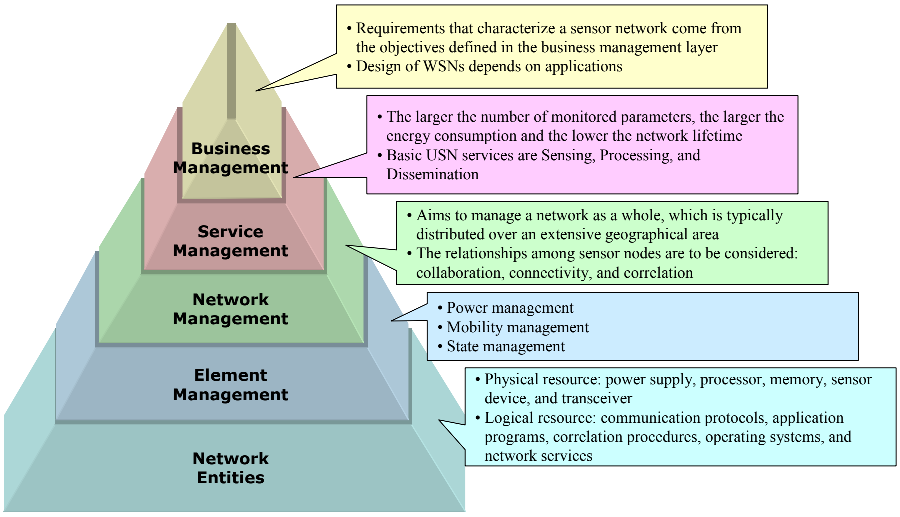
- **Promote resources productivity**
- **Maintain the quality of the services provided**
- **Application-dependent and the management solution design is affected**



- **Developing management solutions for USN**
  - Not trivial
  - Becomes worse due to the physical restrictions of sensor nodes
    - Energy, bandwidth, ……
  - Significantly different with the management of traditional networks

USN Management Architecture & Functions

USN Management Architecture



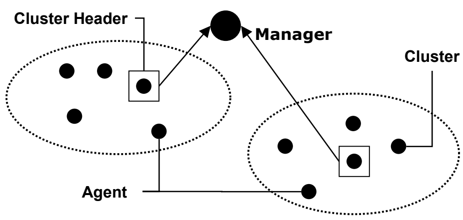
USN Management Functional Areas

	Functions
Fault	▪ Faults in USNs are not an exception and tend to occur frequently, thus fault management is a critical function. ▪ This is one of the reasons that make WSN management different from traditional network management ▪ Self-diagnostic: the network monitors itself and find faulty or unavailable nodes ▪ Self-healing: the network prevents disruptions or that acts to recover itself or the node after the self-diagnostic
Configuration	▪ Self-organization: is the property which the sensor nodes must have to organize themselves to form the network ▪ Self-configuration: nodes setup and network boot up must occur automatically
Accounting	▪ It includes functions related to the use of resources and corresponding reports ▪ It establishes metrics, quotas and limits that can be used by functions of other functional areas ▪ It must provide self-sustaining functionalities
Performance	▪ There is a trade-off to be considered: the higher the number of managed parameters, the higher the energy consumption and the lower the network lifetime ▪ On the other hand, if enough parameter values are not obtained, it may not be possible to manage the network appropriately
Security	▪ Security functionalities for USNs are intrinsically difficult to be provided because of their ad-hoc organization, intermittent connectivity, wireless communication and resource limitations ▪ A WSN is subject to different safety threats: internal, external, accidental, and malicious

Related Research on USN Management Architecture

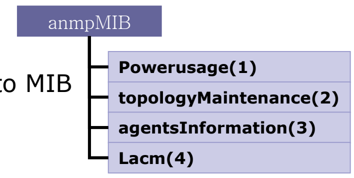
ANMP

- **ANMP**
  - A protocol for managing mobile wireless ad-hoc networks
    - Focuses on data collection, configuration, fault and security management
  - Uses hierarchical clustering of nodes
    - Helps to reduce exchanges between manager and agents
    - Easier to keep track of roaming nodes
  - Fully compatible with SNMPv3
  - Includes enhanced security features
- **Architecture**
  - Hierarchical
  - 3-Level



ANMP: Data Collection

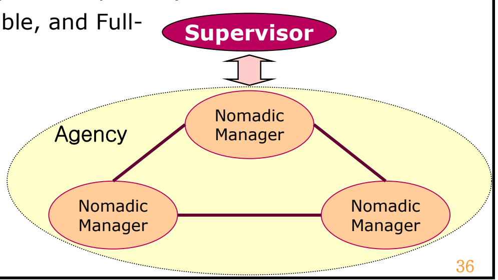
- **ANMP Clustering**
  - Formed for management purposes only - different from those formed for routing purposes
  - Dynamic structures – number and composition of nodes change over time
  - Nodes acting as cluster head may also change
  - Two algorithms proposed for clustering:
    - Graph based clustering (graphic view of the net; each node is no more than one or two hops away from the cluster head)
    - Geographical clustering (based on spatial density of nodes using latitudes and longitude information)
- **Data Collection**
  - Every node runs Anmp locally
  - A new MIB, called Anmp MIB added to MIB



ANMP MIB

Guerrilla Management

- **Guerrilla Management**
  - A supervisor/agency architecture for scalable and cooperative management
  - Uses mobile code techniques for nomadic and active management
  - Uses a dynamic adaptive protocol for clustering and selecting nomadic managers
  - Nodes range in functionality and capability
    - SNMP-capable, Probe-capable, and Full-featured



GMIB: Guerrilla MIB

- **Nomadic Manager**
  - Collaborates autonomously to manage the entire ad hoc network with minimal help from the supervisor
    - Role change
    - Load sharing - cloning itself into another node
    - Spawning and merging
- **GMIB (Guerrilla MIB)**
  - A data structure equivalent to a SNMP MIB
    - An aggregation of management information collected from neighbor nodes via probes
    - Maintained inside NMM
  - Also includes
    - Management information (e.g., neighbor information) in the probe processing modules
  - Can be accessed by both the NMM and incoming probes
    - Modeled as a branch in a SNMP MIB

MANNA

- **Wireless Sensor Network (WSN) Functionalities**
  - Another abstraction level to include the network functionalities
  - Useful in developing various network management models
- **Identifies a set of WSN-specific Managed Objects mostly derived from OSI**
- **Management Architectures**
  - Functional
  - Information
  - Physical

MANNA Architecture

- **Functional Architecture**
  - Describes the distribution of management functionalities among manager, agent, and management information base (MIB)
  - Covers variety of manager-agent models
    - MANNA Manager
    - MANNA Agents
- **Informational Architecture**
  - Two Object Class Type
    - Managed Object Classes
    - Support object classes

Specific Management Functions of USN

Power Management
Topology Management
Security Management
Context-Awareness Management

Power Management

- **Manages how a sensor node uses its power**
- **Example**
  - Sensor node may turn off its receiver after receiving a message from one of its neighbors
    - avoid getting duplicated messages
  - When the power level of the sensor node is low
    - Broadcasts to its neighbor when it is low in power
    - Cannot participate in routing messages
    - Reserve the remaining power for sensing
- **Requirements**
  - Using battery
  - Limited Power
  - Expand the life time of sensor node
  - Reduce the overhead

Simple Routing ⟺ **Processing**

Power Management in Protocol Layer

- **Physical layer**
  - Low Power Modulation Scheme
  - Transceiver, Sensor, Process : Small, Low Power, Low Cost
- **Data link layer**
  - Energy efficiency MAC protocol
    - Adaptive duty cycling – S-MAC, ASCENT, SPAN
    - Wake up on-demand – STEM, Wake-on-Wireless
  - Reduce the collision, signaling, frame overhead
  - Power saving mode (ex. On/Off mode)
- **Network Layer**
  - Energy-efficiency routing
  - Energy-efficiency data aggregation algorithms
  - Location based routing
- **Transport Layer**
  - Use UDP message protocol between Sink and Sensor node
  - Limited memory and processing power
- **Application Layer**
  - Energy-efficiency Applications

Topology Management

- **Goal**
  - is to coordinate the sleep transitions of all nodes, while ensuring adequate network connectivity, such that data can be forwarded efficiently to the data sink.
- **Requirements**
  - Heterogeneous node
  - Data discovery & data dissemination
  - Limited memory & power constraint
  - Application requirements
  - Node mobility
- **Ad-hoc Self-organization**
  - LCA (Linked Cluster Algorithm)
  - LAA (Link Activation Algorithm)
  - DEA (Distributed Evolution Algorithm)

Topology Management (Cont.)

- **SMACS (Self-Organizing Medium Access Control for Sensor networks)**
- **EAR (Eavesdrop And Register)**
  - BI (Broadcast Invite)
  - MI (Mobile Invite)
  - MR (Mobile Response)
  - MD (Mobile Disconnect)
- **SAR (Sequential Assignment Routing)**
- **SWE (Single Winner Election)**
- **MWE (Multi Winner Election)**

Security Management

- **Requirements**
  - Peanut CPU (slow computation rate)
  - Battery power: trade-off between security and battery life
  - Limited memory
  - High latency: conserve power, turn on periodically
- **Security Management in USN**
  - Applications need security (privacy)
  - Absence of security enables attacks such as spoofing & replay attacks, resulting in DoS or system compromise
  - Intrusion prevention : First line of defense
  - Intrusion detection : Second line of defense
- **Main Security Threats in USN**
  - Radio links are insecure
  - Sensor nodes are not temper resistant
- **Attacker types**
  - Mote-class
  - Outside / inside

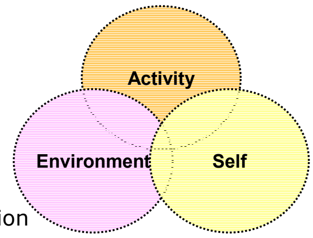
Security Management (Cont.)

- **Attacks**
  - Physical attack
  - Denial-of-service
  - Battery exhaustion
  - Clock synchronization
  - Location discovery
  - Attacks on routing
    - spoofed, altered, or replayed routing information
    - selective forwarding
    - sinkhole attack
    - sybil attack
    - wormholes
    - HELLO flood attacks
    - acknowledgment spoofing

Security Management (Cont.)

- **Countermeasures**
  - Link layer encryption – selective forwarding
  - Using a counter – Replay attacks
  - Limiting the number of neighbors per node – Insider attacks
  - Bi-directionality of the link – HELLO flood
  - Geographically routing – Wormhole attacks

Context Management



- **Gathering the "User Context"**
- **Requirement**
  - User intent prediction
  - Application deployment support
  - Runtime context service
  - Real-time service
  - Inter-user coordination and collaboration
- **Context**
  - Any information that can be used to characterize the situation of an entity
    - Considered relevant to the interaction of an entity
    - Considered relevant to the interaction between a user and an application, including themselves
- **Context Model**
  - The ACTIVITY – behavior, task
  - The ENVIRONMENT – physical status, social surroundings
  - The SELF – status of device itself

Context Management (cont')

- **Key Components**
  - Context discovery and acquisition
  - User interface
  - Context management and modeling
  - Context composition and gathering
- **Group Context Management**
  - Enable syntactic and semantic interoperability between context- aware applications
  - Enable seamless integration of various kinds of contexts and make it easy to be inferred
- **User Context**
  - User intent prediction
  - Application development support
  - Runtime context service
  - Inter-user coordination and collaboration

Conclusion

- **Brief Overview on Ubiquitous Sensor Network Technology**
  - Representative Projects related to USN
  - Sensor Network Protocol Stack
  - Standardization Activities
- **USN Management Requirements**
- **USN Management Architecture**
- **USN Management Functions**
  - Related Research on USN Management Architecture
- **Specific USN Management Functions**
  - Power Management
  - Topology Management
  - Security Management
  - Context Management
- **Future Works**

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