MACs for Sensor Networks

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COMPASS Talk

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Medium Access Control

- Responsible for single-hop data transfer
- Provides efficient access to shared media
- Controls access to radio
- Provides other network related services
  - Localization
  - Clock synchronization
  - Neighborhood discovery

MAC Approaches

- Contention-Based: Using local coordination
  - Flexible with increased traffic fluctuations and node failures or additions
  - Sources of overhead – Idle listening, Packet collisions, Control packet overhead
- Schedule-Based:Using central coordination
  - Collision-free and no idle listening
  - Reduced flexibility to handle variable traffic and changing neighborhood

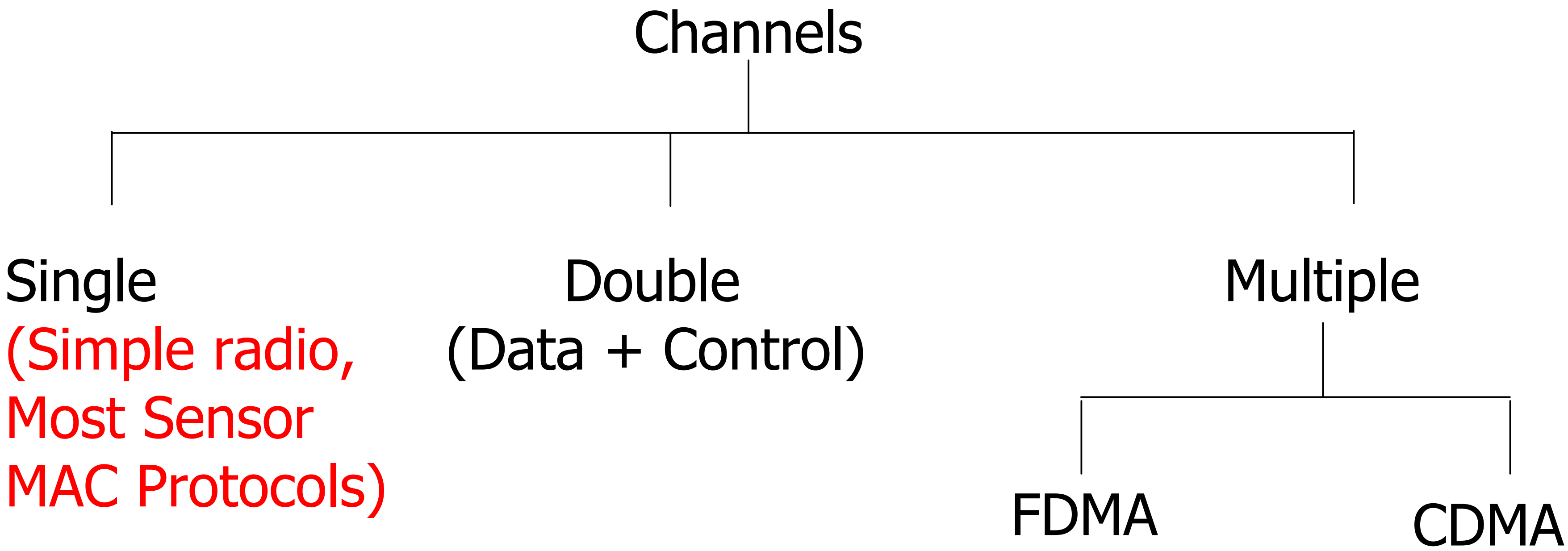
Sensor Network: Requirements and Opportunities

- Significant: Energy efficiency & scalability
- Reduction of significance: Fairness, throughput, utilization, latency
- (Can/Should) Adapt to communication patterns
  - Many-to-one (Convergecast)
  - Local gossip
- (Should) Adapt to network conditions

Survey of MAC Protocols

- Classification according to 3 design decisions
  - Number of physical channels used
  - Organization of the nodes
  - Notification of the nodes

Multiple Channels



Notification of the nodes

Notification

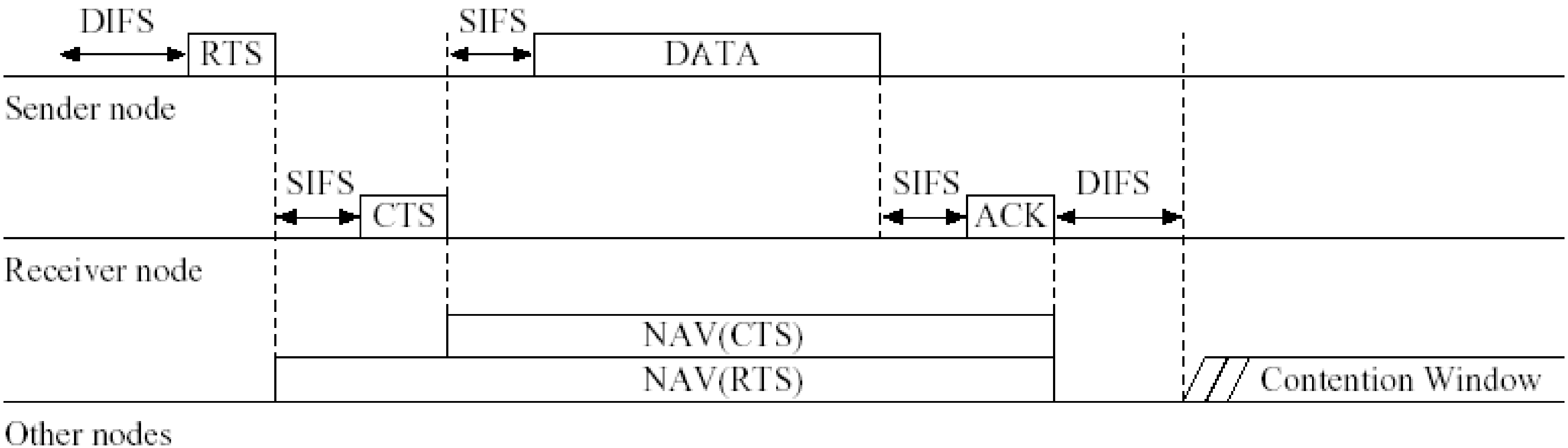
- Listening (CSMA)
- Wakeup (Need more than one channel)
- Schedule (TDMA)

Organization of the nodes

Organization

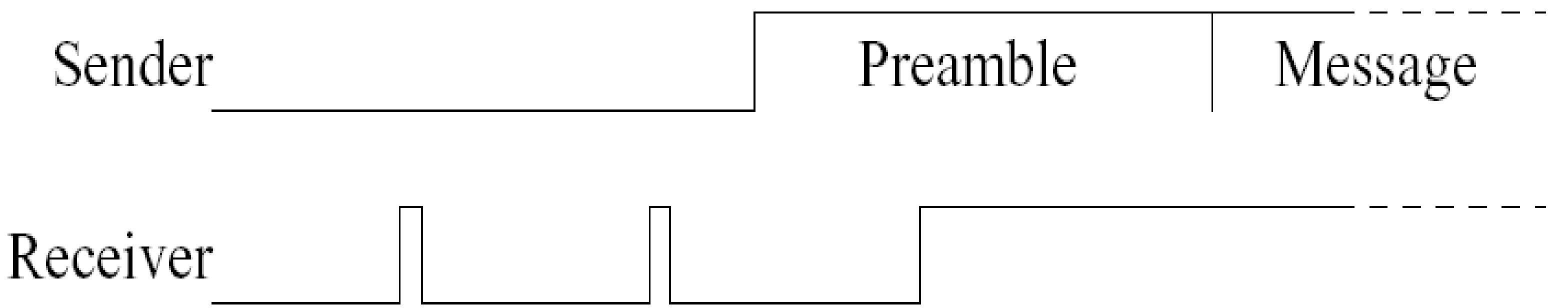
- Random (Flexible)
- Slotted (Middle-ground)
- Frames (Efficient)

Random Access Protocols



- IEEE 802.11 access control
- Power Save (PS) Mode: Access point buffers traffic for the nodes

Random Access Protocols

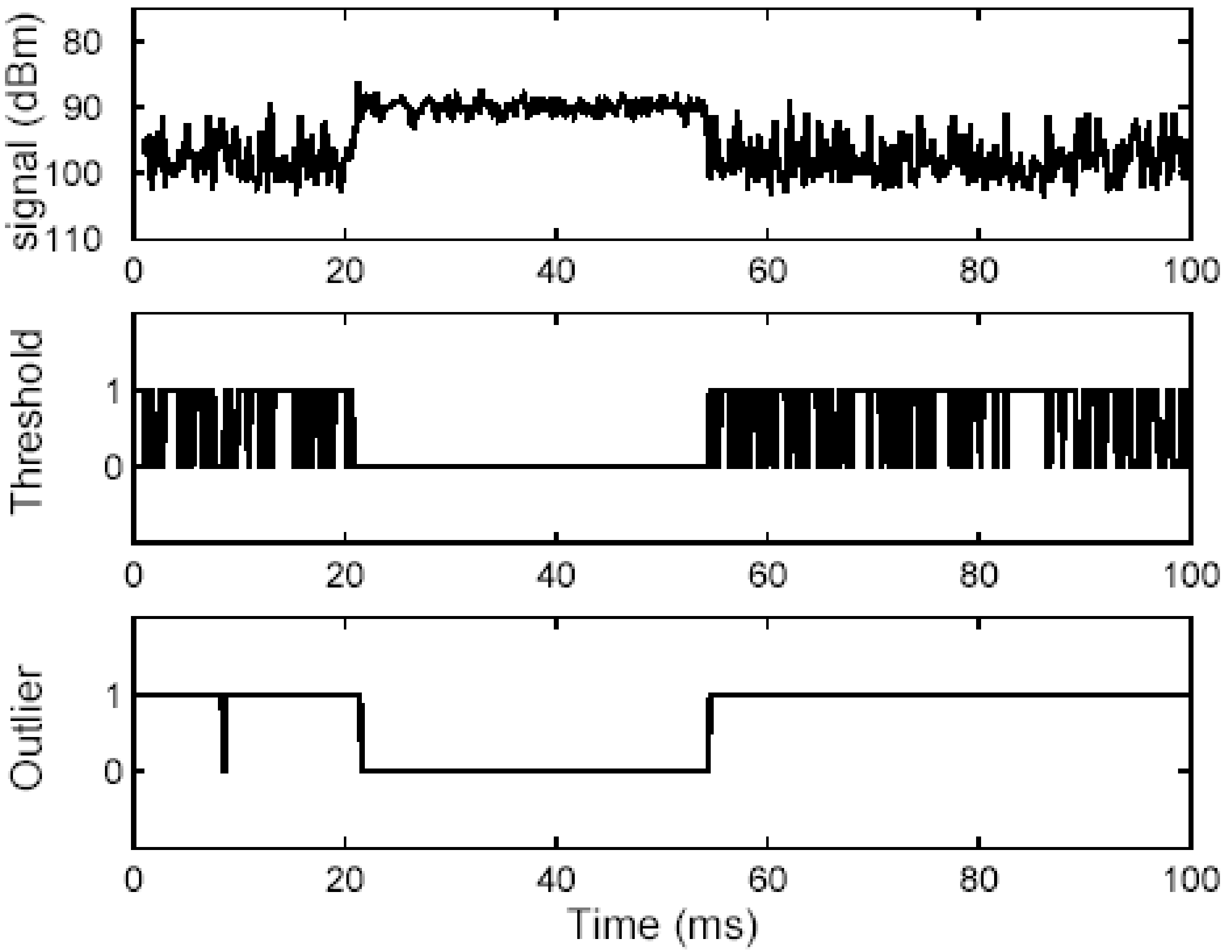


- Preamble notifies receivers of upcoming transfer
- Shifts cost from receivers to transmitters
- Low Power Listening(LPL) and Preamble Sampling

[Hill,Micro'02][WiseMAC,SenSys'03]

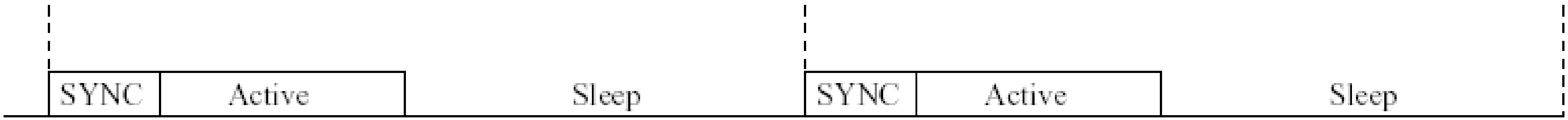
Random Access Protocols

- Accurately determines if channel is clear
- Clear-Channel Assessment(CCA)
- LPL, CCA and ACK can be tuned by application [BMAC,SenSys'04]



Rice Monarch Project

Slotted Protocols

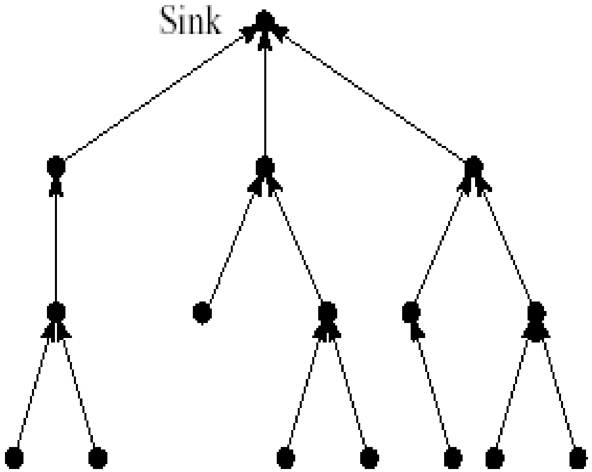


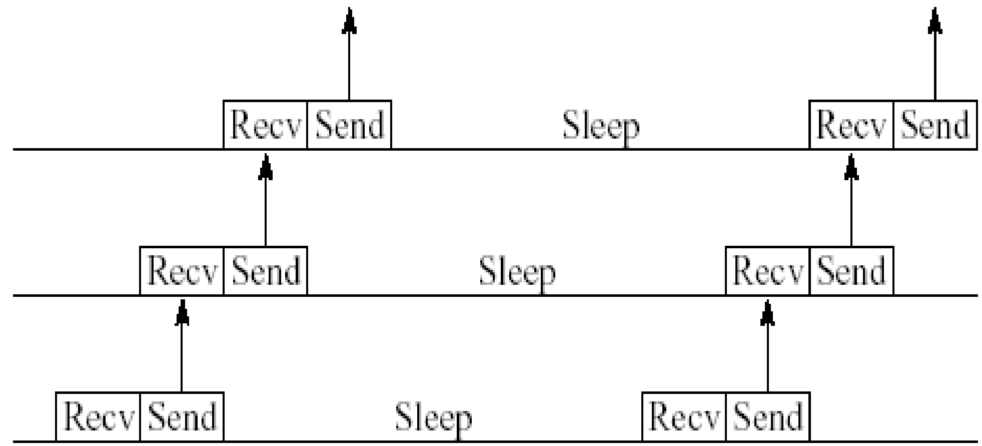
- Synchronize nodes into slots
- Implement duty cycle within each slot, which determines energy saved
- 802.11 style data transfer using RTS/CTS
- Overhearing avoidance & Streaming sequence of messages[SMAC, Infocom'02]

Slotted Protocols

- Adaptive duty cycle over SMAC
- Nodes have very short *Active* periods, and go to sleep if no traffic is detected
- Automatically adjusts to fluctuations in traffic [TMAC, SenSys'03]

Slotted Protocols





- Low latency for Convergecast only
- Slot sequences are staggered
- Overflow policy adapts to the traffic load [BMAC, WMAN'04]
- Perfect match for a MAC for TreeCast [WMAN'04]

Schedule-based Protocols

- Energy-efficient and fixed latency
- Challenge is to adapt TDMA protocols to work without any infrastructure
- Assumption 1: Clock synchronization present or achieved through TDMA frames
- Assumption 2: Interference range is equal to the transmission range

Sink-Based Scheduling

- A central base-station, or sink or cluster-head computes the TDMA schedule
- Sensors inform cluster-heads of traffic demands, which are addressed in the next scheduled frame

[IBM Systems Journal, 1995]

- Cluster-heads can be rotated to save energy for that node [LEECH, PACT, BMA]

Distributed Scheduling

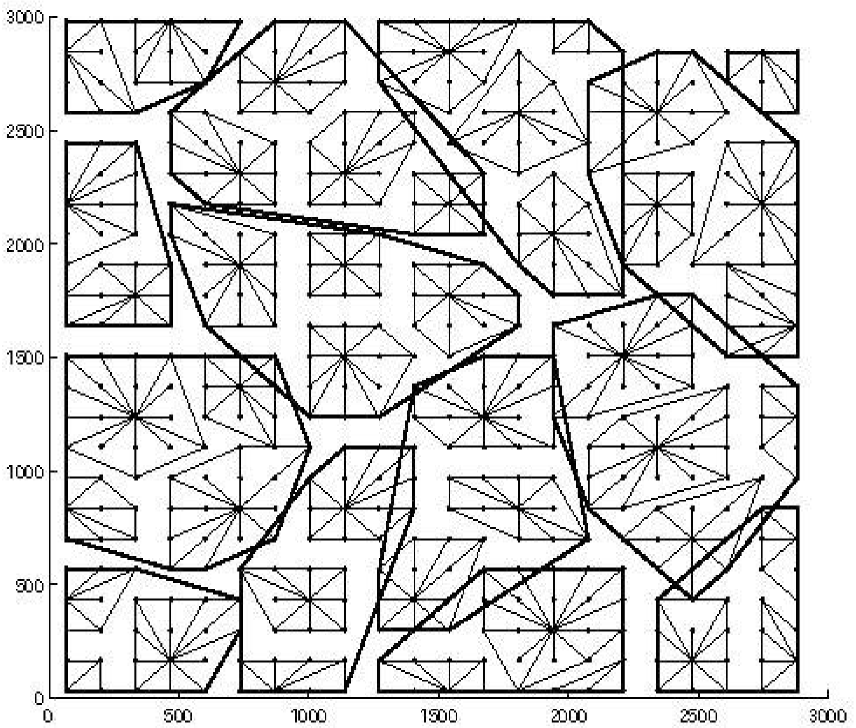
- Nodes know the 2-hop neighborhood
- Nodes broadcast their future traffic demand
- Sufficient information to choose one transmitter in a collision-free way
  - Priority given by hash fn of node and slot id
- Completely general communication assumed

[NAMA, MobiCom'01][TRAMA, SenSys'03]

Weakness: Schedule-based approaches

- Compromise on latency bound
  - Much worse than contention based approaches
- Application traffic pattern not harnessed
  - Many traffic demands are strictly periodic
  - Source and destination is not any to any
- Network conditions might change
  - Should provide same service to data service layer, even with changing conditions
- Sink-based scheduling does not take 2-hop neighborhood into account

COMPASS: Multi-scale Architecture



- Multi-scale architecture enables
  - Local collaboration
  - Multi-resolution data
  - Extreme scalability
- Abstraction middleware enables
  - Ease of programmability
  - Efficient networking

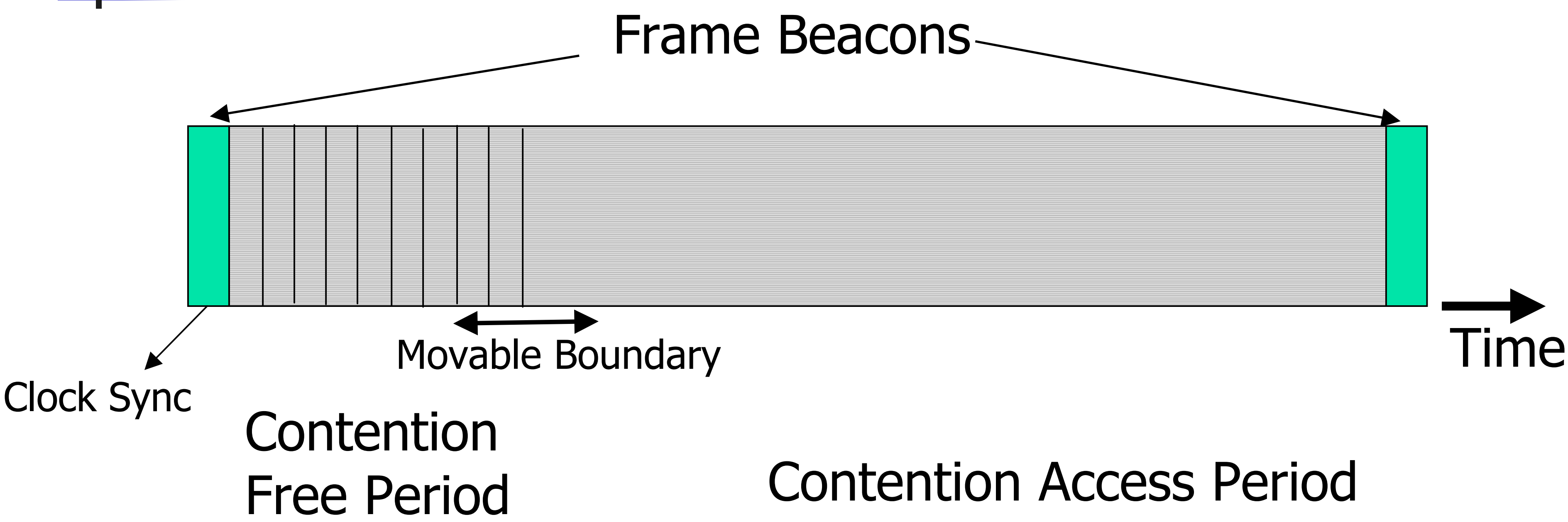
COMPASS MAC

1. Energy-efficient with real-time guarantees
2. MAC to handle communication in COMPASS
3. Provide reliability semantics to application, independent of network condition

1. Design

- Time-frame divided into two parts
- **Synchronized Contention Free Period**
  - Periodic deterministic application traffic
  - Example: Periodic sample of temperature
- **Event-driven Contention Access Period**
  - Event-driven Real-time traffic
  - Example: Intrusion detection, Fire, etc
- Boundary between these changes with load

Time Frame



- The Periods might potentially interleave to guarantee real-time requirement

2. Communication Interfaces

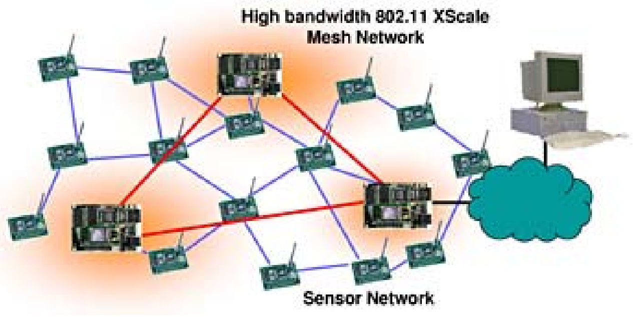
- MAC gets information about traffic pattern through the **NPI** provided by the Data Service (Routing) Layer
  - Put/Get – Corresponds to down/up stream traffic
  - Parent/Peer/Cell – Corresponds to scope of communication
  - Each interface specifies required periodicity
- All nodes know the periodic traffic demand

Collision-free Scheduling

- Collision-free slot assignment
  - 2-hop information known. [Needed for optimal cell flooding]
  - Nodes know traffic demands
  - Every node creates slot schedule across cluster boundaries [Similar to NAMA, TRAMA]
- Cluster-heads use these slot schedules to create compact TDMA schedule in it's Contention-Free Period

Discussion

Sensor Node Applications



Source: www.intel.com

- Monitor and control traffic
- Distributed surveillance
- Industrial automation
- Smart Buildings
- Preventive maintenance
- Pervasive computing
- Health monitoring
- Environment monitoring
- etc

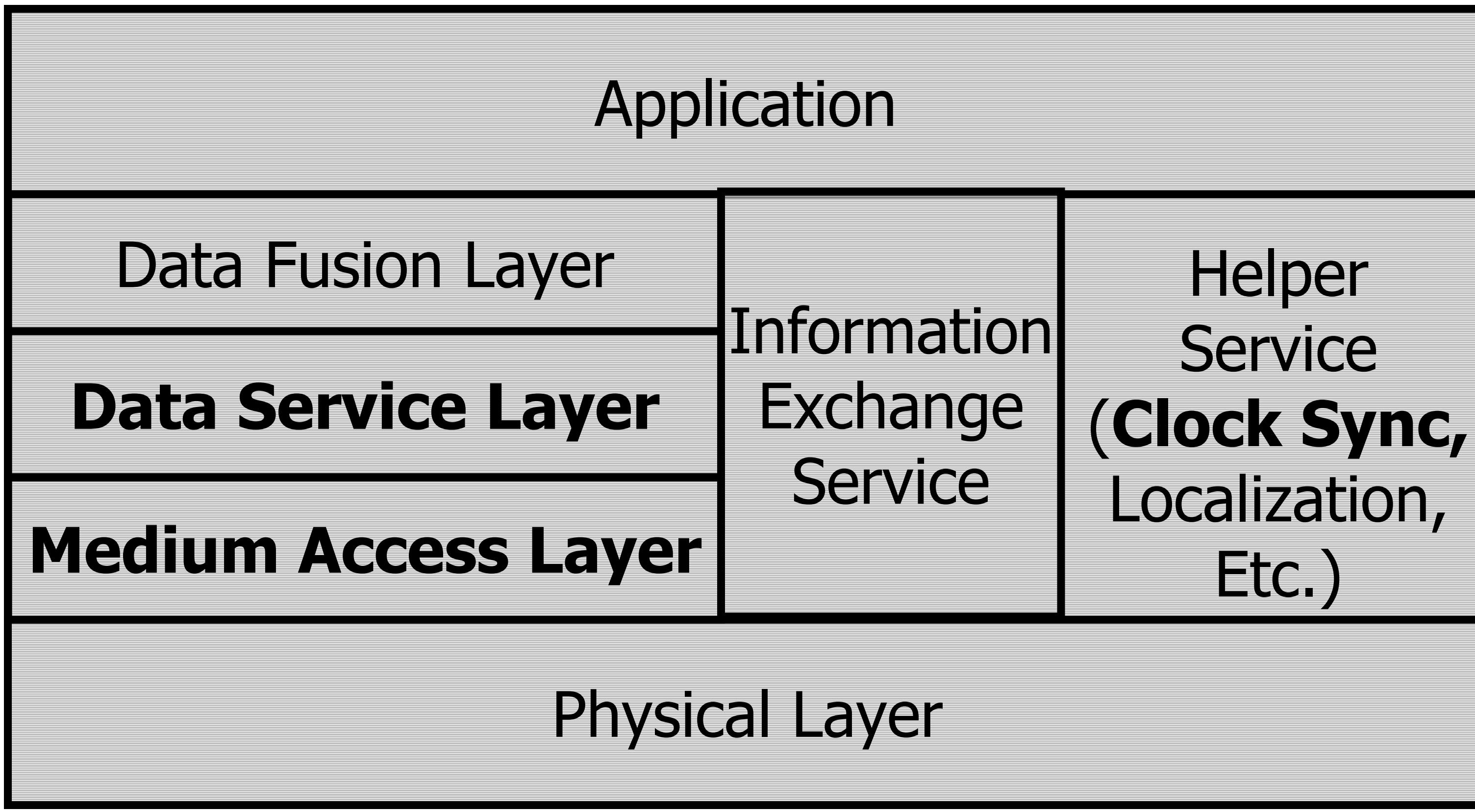
Key Point

- In wireless ad hoc sensor networks (WASNs), there is simultaneously a need and an opportunity for optimizing the protocol behavior to match sensor-based applications.
- In my thesis, I adapt some key networking protocols to align with application-need for better efficiency

State of the ART

- Protocols not yet adaptive
- Currently, applications and networking are developed separately. No interaction implies valuable loss of information
- No joint development of Routing and Medium access

SensorStack: Our Architecture



Adaptive Clock Synchronization

- Accuracy of synchronization is tradeoff with
  - Application Need
  - Resource Constraints
- Probabilistic protocol based on deterministic RBS Protocol
- Converts service specification to actual protocol parameters
- Given (P,E) P = Probability that e is met, E = Maximum Synchronization Error, derive no. of messages & period of sync

Theorem 1: $P(|\epsilon| \leq \epsilon_{max}) = 2\, erf\left(\frac{\sqrt{n}\,\epsilon_{max}}{\sigma}\right)$

Theorem 2: $\gamma_{max} = \epsilon_{max} + (T_{sync} + \sigma_{max})\rho$

Wireless Sensor Networks Characteristics

- Adaptability to applications
  - Limited set of application requirements
- Energy Optimization is critical
  - Limited battery capacity
- Data Fusion Capability
  - In-network processing (E.g.: Averaging)
- Data-Centric Routing
  - Individual sensor not important, but the sensed data is important
- Resource Constraints
  - Physical form factor
- Large Scale
  - Traditional stateful routing not possible

Application-specific Adaptation

- Adaptive Clock Synchronization (IPSN, Apr 04)
- TreeCast: Addressing and Routing Architecture (IPDPS Workshop, Apr 04)
- COMPASS: Multi-scale Communication (Submitted)
- Sensor Medium Access Control (Work in Progress)