Wireless Multimedia Sensor Networks (WMSNs)

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Outline

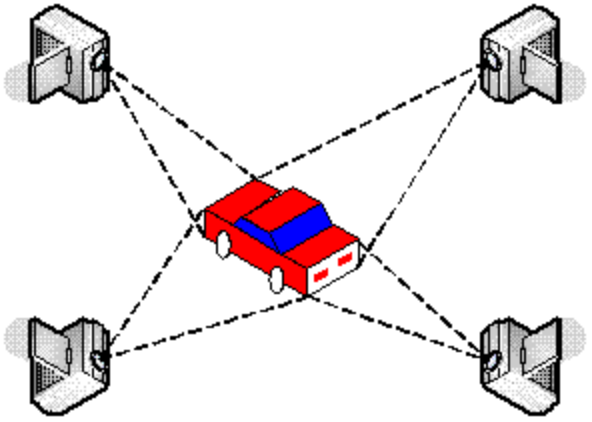
- Introduction to WMSN
- Deploying WMSN
- Layered Research Issues (Application, Transport and Network)
- Cross-layer and Other Research Issues

Introduction

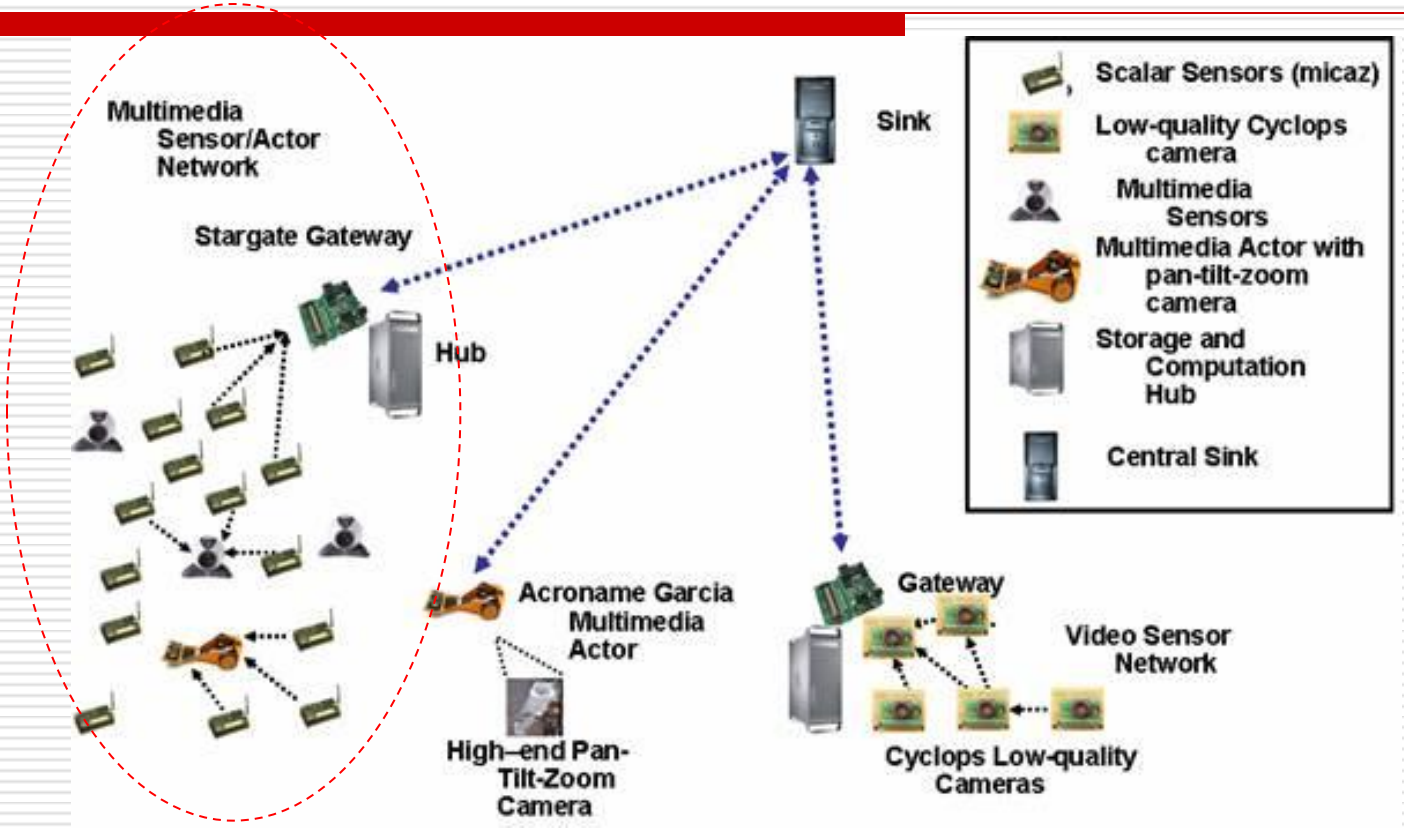
- Develop of inexpensive hardware
  - CMOS cameras
  - Microphones
- It is possible to ubiquitously capture multimedia content from the environment
- Wireless Multimedia Sensor Networks:
  - Networks of wirelessly interconnected devices
  - Allow retrieving video and audio streams, still images, and scalar sensor data.

Wireless Multimedia Sensor Networks

- Low-cost multimedia devices
  - CMOS cameras
  - Microphones
- Sensor motes attached with a multimedia device
- Provides multiple point of view perception
  - Since it employs large number of nodes



Wireless Multimedia Sensor Networks



Transmitting multimedia streaming data in wireless sensor networks

Applications of WMSNs

- Multimedia surveillance sensor networks
  - Video and audio sensors will be used to enhance and complement existing surveillance systems against crime and terrorist attacks.
- Storage of potentially relevant activities
  - Thefts, car accidents, traffic violations
- Traffic avoidance, enforcement and control systems
  - To monitor car traffic in big cities or highways
  - Traffic routing advice to avoid congestion

Applications of WMSNs

- Advanced health care delivery
  - to provide ubiquitous health care services.
  - Patients will carry medical sensors to monitor Vital signs:
    - Body temperature,
    - Blood pressure,
    - Pulse oximetry,
    - ECG,
    - Breathing activity
  - Remote medical centers will perform advanced remote monitoring of their patients via video and audio sensors

Applications of WMSNs

- Automated assistance for the elderly and family monitors
  - To monitor and study the behavior of elderly people
  - To identify the causes of illnesses that affect them
- Environmental monitoring
  - Use acoustic and video feeds
- Person locator services
  - To locate missing persons, or identify criminals or terrorists.
- Industrial process control
  - To support a manufacturing process such:
    - Semiconductor chips
    - Automobiles
    - Food or pharmaceutical products

Enhancement in Surveillance Systems

- Enlarging the view
  - The Field of View (FoV) of a single fixed camera, is limited.
  - A distributed system of multiple cameras helps overcoming occlusion effects.
- Enhancing the view
  - Provide enhanced understanding and monitoring of the environment.
  - Overlapped cameras can provide different views of the same area or target
- Enabling multi-resolution views
  - to provide a multi-resolution description of the scene and multiple levels of abstraction.

Challenges in QoS Delivery in WMSNs

- Resource constraints
  - Sensor devices are constrained in terms of
    - Battery,
    - Memory,
    - Processing capability,
    - Achievable data rate
- Variable channel capacity
  - The attainable capacity of each wireless link depends on the interference level perceived at the receiver

Challenges in QoS Delivery in WMSNs

- Cross-layer coupling of functionalities
  - There is a strict interdependence among functions handled at all layers of the communication stack.
- Multimedia in-network processing
  - WMSNs will allow performing multimedia in-network processing algorithms on the raw data.

Factors Influencing The Design of WMSNs

- Application-specific QoS requirements
  - The wide variety of applications envisaged on WMSNs will have different requirements
- High bandwidth demand
- Multimedia source coding techniques
- Multimedia in-network processing

Factors Influencing The Design of WMSNs

- Power consumption
- Flexible architecture to support heterogeneous applications
- Multimedia coverage
- Integration with Internet (IP) architecture
- Integration with other wireless technologies

WMSNs Architecture

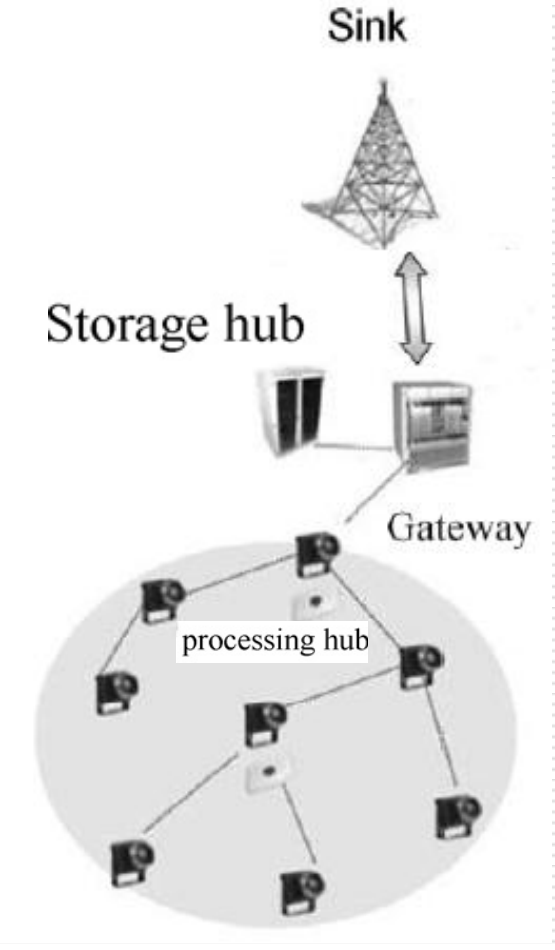
- Single-tier network
  - Flat homogenous architecture
- Single-tiered clustered architecture
- Multi-tiered Network

Flat Homogenous Architecture

- Single-tier network of homogeneous sensor nodes.
- Each sensor performs all possible application tasks
- Every sensor has the same physical capabilities
- Sensors can only interact with neighboring sensors
- May not always be suited to handle the amount of traffic generated by multimedia applications

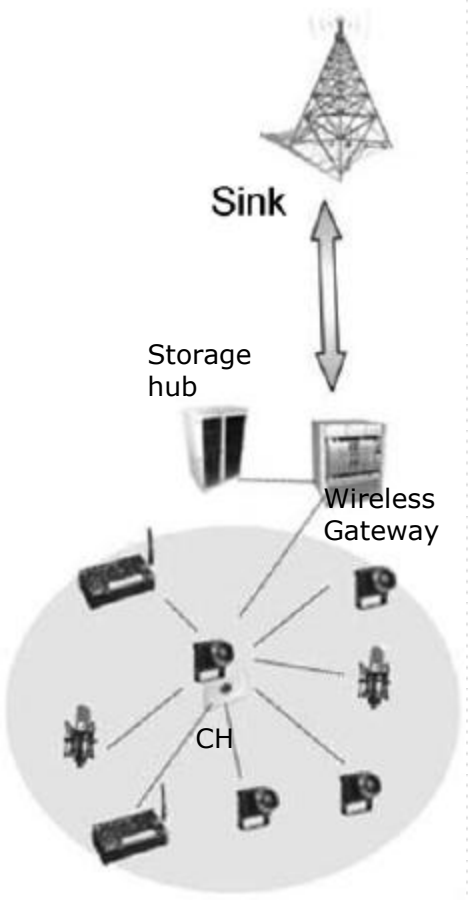
Single-tier Network

- Homogeneous sensors
- Processing hubs:
  - A subset of the deployed sensors which have higher processing capabilities
  - The union of the processing hubs constitutes a distributed processing architecture.
- Gateway:
  - The multimedia content gathered is relayed to a wireless gateway through a multi-hop path.
  - The gateway is interconnected to a storage hub
- Storage hub
  - Is in charge of storing multimedia content locally for subsequent retrieval.



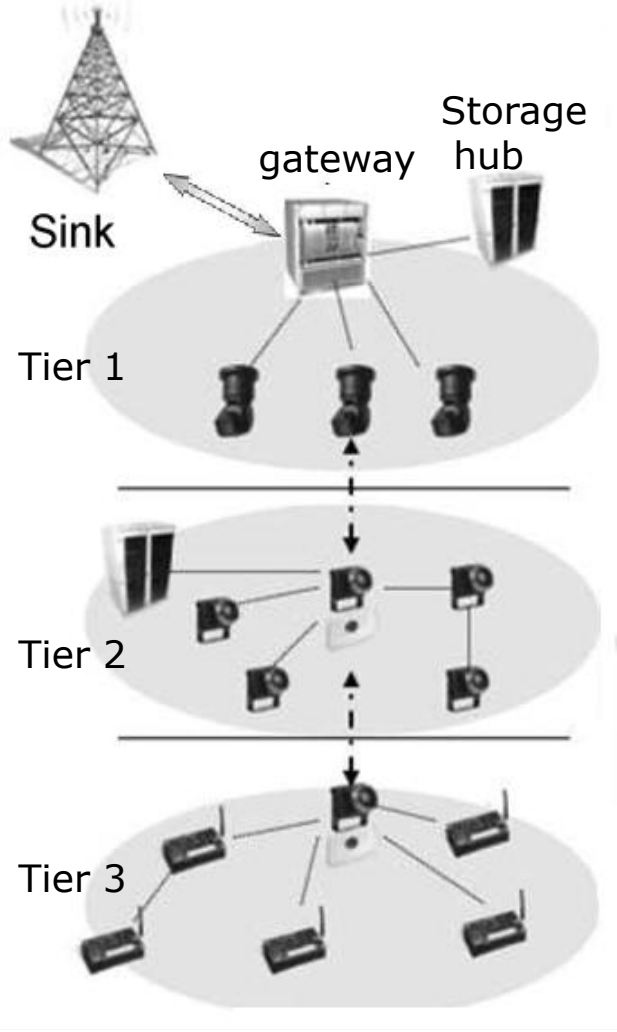
Single-tiered Clustered Architecture

- Heterogeneous sensors
- Video, audio, and scalar sensors relay data to a central Cluster Head (CH)
- The cluster head relays the gathered content to the wireless gateway and to the storage hub

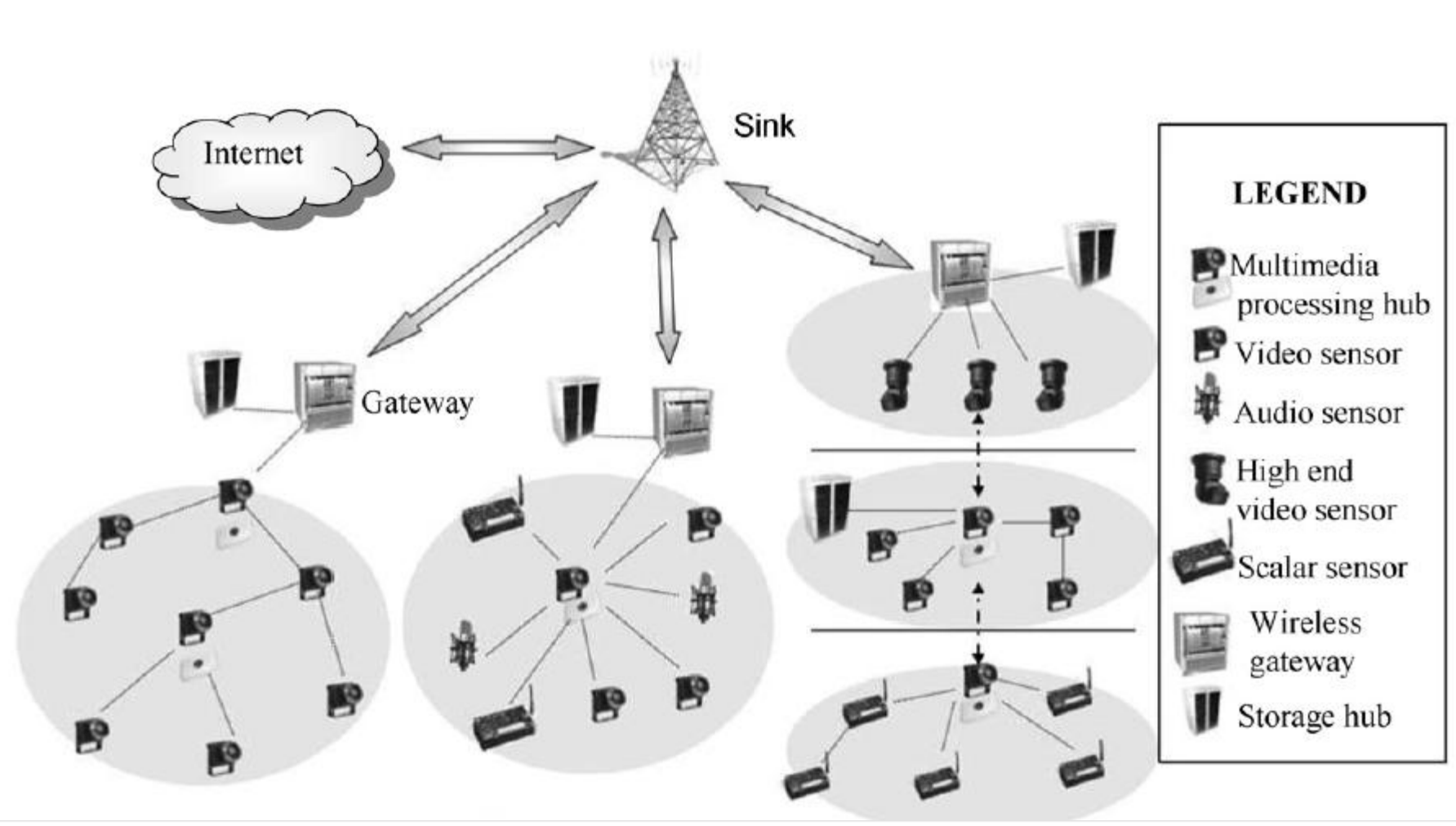


Multi-tiered Network

- Heterogeneous sensors
- Each tier is in charge of a subset of the functionalities.
- Low-power scalar sensors are in charge of performing simpler tasks
- High-power devices are responsible for more complex tasks.
- Data processing and storage can be performed in a distributed fashion at each different tier.



WMSNs Architecture



Single-tier vs. Multi-tier Sensor Deployment

- Single-tier
  - Homogeneous sensors
  - Each sensor performs all possible application tasks
- Multi-tier
  - Heterogeneous elements
  - Resource-constrained, low-power elements are in charge of performing simpler tasks
    - Such as detecting scalar physical measurements
    - Motion or intrusion detection
  - Resource rich, high-power devices take on more complex tasks:
    - Object recognition and tracking

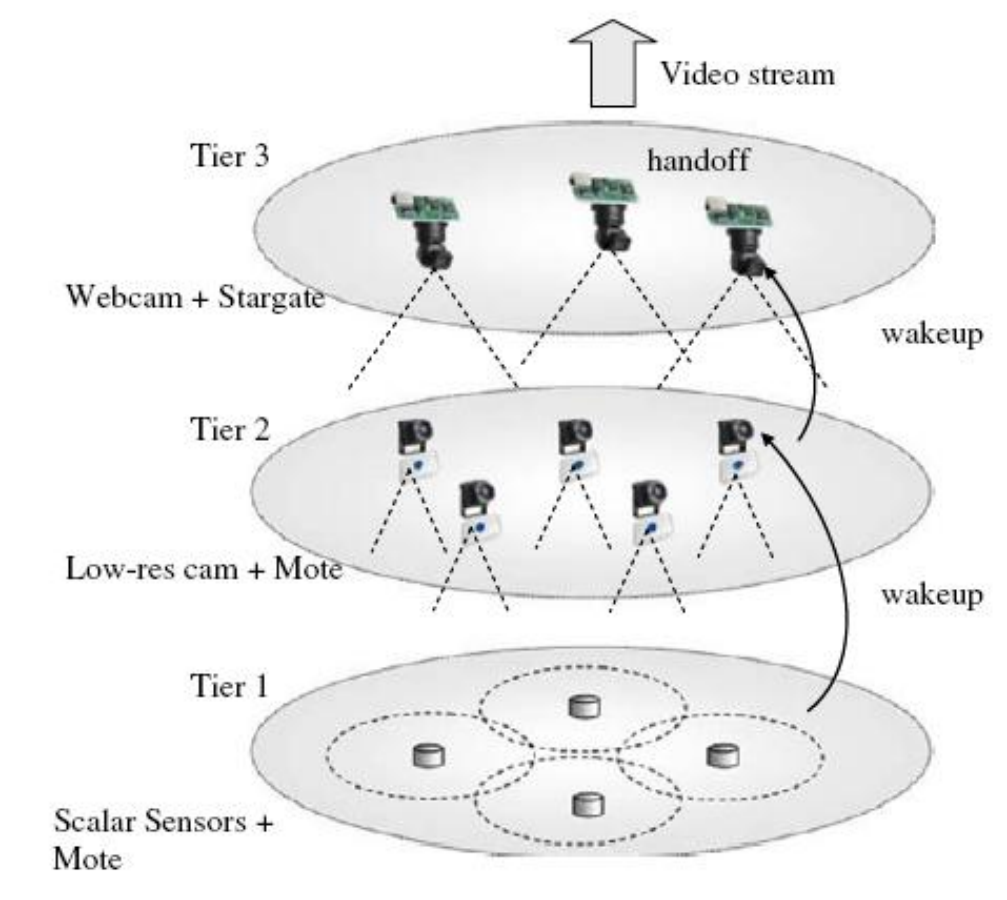
Coverage

- Multimedia sensors generally have larger sensing radii
- They are sensitive to the direction of data acquisition.
- Cameras can capture images of objects or parts of regions that are not necessarily close to the camera itself.
- Image can obviously be captured only when there is an unobstructed line-of-sight between the event and the sensor

Sens-Eye : An Examples of Deployed WMSN

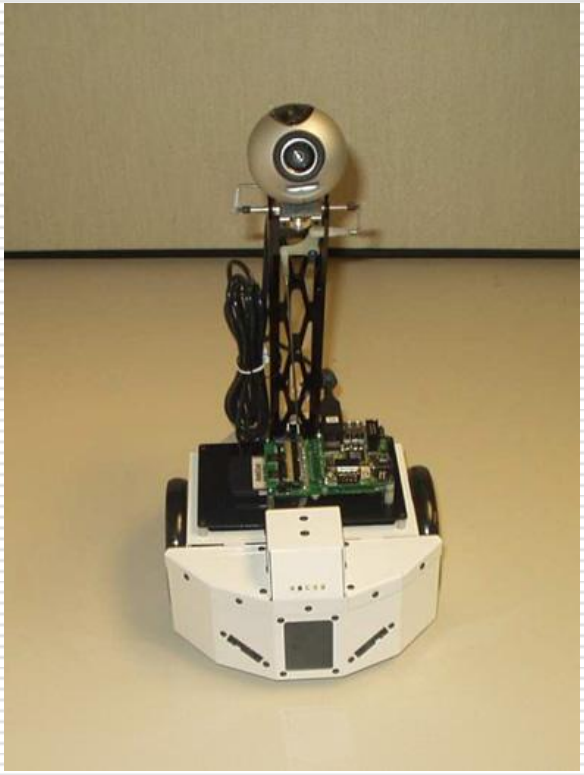
- The surveillance application consists of three tasks:
  - Object detection
  - Object Recognition
  - Object tracking
- A three-tier network of heterogeneous wireless nodes and cameras
  - The lowest tier consists of:
    - Low-end devices
    - MICA2 Motes with 900MHz radios interfaced
    - Scalar sensors, e.g., vibration sensors.
  - The second tier is made up of motes equipped with low fidelity Cyclops or CMUcam camera sensors.
  - The third tier consists of Stargate nodes equipped with webcams.

The Multi-tier Architecture of SensEye



Some Video Sensors

Stargate board interfaced with a medium resolution camera.



a mobile robot with a mounted camera

Challenges of WMSNs

- Application Specific QoS Requirement
- High Bandwidth Demand
  - Transmission of large-sized multimedia content data is expensive
- Multimedia Source Coding Techniques
  - Compressing Algorithms
- Multimedia in-network processing
  - Data aggregation and processing
  - Eliminating redundancy to some extent
- Multimedia Coverage
- Integration with IP and other wireless devices
  - In the future WMSNs should be accessible from the Internet

Collaborative in-network Processing

- A great interest in the context of a WMSN.
- The objective:
  - To avoid transmitting large amounts of raw streams to the sink by processing the data in the network to reduce the communication volume.
- A fundamental question
  - Can this processing be done on sensor nodes of multi-functional sensors?

Application Layer of WMSNs

- The services offered by the application layer include:
  - Providing traffic management and admission control functionalities
  - Performing source coding according to application requirements and hardware constraints
  - Providing flexible and efficient system software to export services for higher-layer
  - Providing primitives for applications to leverage collaborative, advanced in-network multimedia processing techniques

Traffic Classes

- Real-time, Loss-tolerant, Multimedia Streams.
  - Video and audio streams
  - Strict delay bounds
  - Relatively loss tolerant
    - e.g., video streams can be within a certain level of distortion).
  - High bandwidth demand.

Traffic Classes

- Delay-tolerant, Loss-tolerant, Multimedia Streams.
  - Multimedia streams that, being intended for storage or subsequent offline processing,
  - No strict delay bounds.
  - Needs to be transmitted almost in real-time to avoid excessive losses.

Traffic Classes

- Real-time, Loss-tolerant, Data.
  - Include monitoring data from densely deployed scalar sensors
    - light sensors
    - loss-tolerant snapshot multimedia data
  - Sensor data has to be received timely
  - The application is moderately loss-tolerant
  - The bandwidth demand is usually between low and moderate.

Traffic Classes

- Real-time, Loss-intolerant, Data.
  - May include data from time-critical monitoring processes such as distributed control applications.
  - The bandwidth demand varies between low and moderate.

Traffic Classes

- Delay-tolerant, Loss-intolerant, Data.
  - May include data from critical monitoring processes
  - Low or moderate bandwidth demand that require some form of offline post processing.
- Delay-tolerant, Loss-tolerant, Data.
  - May include environmental data from scalar sensor networks
  - Non-time-critical snapshot multimedia content, with low or moderate bandwidth demand.

Transport Layer

- Effects of congestion:
  - In WMSNs, the effect of congestion may be even more pronounced as compared to traditional networks.
  - It may cause rapid depletion of the node's energy.
  - Congestion control algorithms may need to be tuned for:
    - Immediate response
    - Avoid oscillations of data rate

Transport Layer

- Packet re-ordering due to multi-path:
  - Multiple paths may exist between a given source-sink pair
  - The order of packet delivery is strongly influenced by the characteristics of the route chosen.
  - information that cannot be used in the proper sequence becomes redundant
  - Stressing on the need for transport layer packet reordering.

TCP/UDP and TCP Friendly Schemes for WMSNs

- For real-time applications like streaming media, the UDP is preferred over TCP
- Timeliness is of greater concern than reliability
- Problems of UDP:
  - Effect of dropping packets in UDP
  - Support for traffic heterogeneity
    - The UDP header has no provision to allow any description of traffic classes

→TCP with appropriate modifications is preferable over UDP for WMSNs

TCP/UDP and TCP Friendly Schemes for WMSNs

- Problems of TCP:
  - Effect of jitter induced by TCP
  - Overhead of the reliability mechanism in TCP
    - Distributed TCP Caching (DTC) overcomes these problems by caching TCP segments inside the sensor network
  - Regulating streaming through multiple TCP connections

Network Layer

- Addressing
  - In WMSNs it is required that the individual nodes be monitored via the Internet.
  - Global addressing could be solved by the use of IPv6
    - The sensor can concatenate its cluster ID with its own MAC address to create the full IPv6 address.
    - The 16-byte address field of IPv6 introduces excessive overhead in each sensor data packet.
  - Assign unique network-wide IDs

Network Layer

- Routing classification
  - Network conditions
    - Interference seen at intermediate hops,
    - The number of backlogged flows along a path,
    - Residual energy of the nodes
  - Traffic classes
    - Decide paths based on packet priorities
  - Specialized protocols for real-time streaming
    - Use spatiotemporal forwarding.

MAC Layer

- It is desirable that MAC protocol supports application-specific QoS requirements.
- Multimedia traffic can be classified as separate service classes
  - Different buffering, scheduling and transmission policies are applied
- Classification of research efforts to provide MAC layer QoS
  - Channel access policies,
  - Scheduling and buffer management
  - Error control.

Physical layer

- The Ultra Wide Band (UWB) technology:
  - Low-power consumption
  - High data rate communications within tens of meters
- UWB is an ideal choice for WMSNs.
- UWB signals have been used for several decades in the radar community.
- UWB signals use the spectrum from 3.1 GHz to 10.6 GHz
- Two main variants of UWB:
  - Time-Hopping Impulse Radio UWB (TH-IR-UWB)
  - Multi-Carrier UWB (MC-UWB)

Benefits of TH-IR-UWB for WMSNs

- High data rate
- Very low-power
- Fine delay resolution
- Large processing gain in presence of interference.
- Flexibility
- Integrated MAC/PHY solutions
- Low-power spectral density