WSN Architectures for Intelligent Transportation Systems

By

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Agenda

- Introduction
- WSN Design Requirements
- WSN Architectures
- WSN Architectures for ITSs
- Conclusion & Future Directions

Introduction (1/4)

- Intelligent Transportation Systems (ITSs) use technological advances in information technology to enhance the efficiency of the transportation systems and their associated services
- Improving the efficiency of transportation systems affects both economy and environment
  - Traffic congestion costs US around $200 billions annually (Department of Transportation announcement in 2006)
- Transportation networks should be monitored properly to collect information about important events (traffic congestion, accidents, emergency conditions … etc) and take decisions to alleviate them

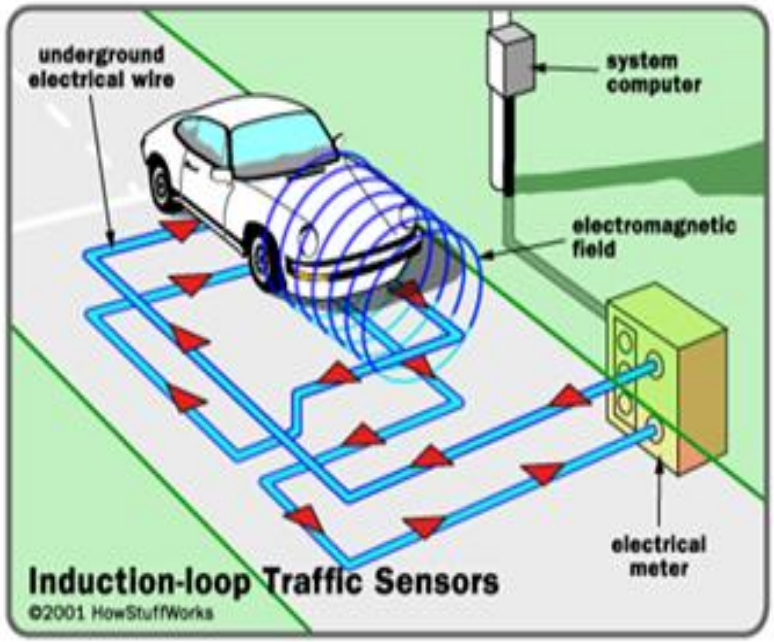
Introduction (2/4)

- ITSs have been traditionally realized by Wired Sensor Networks
  - Wired sensors are bulky, power-hungry, expensive to install, maintain and repair
  - Thus, scalability of ITSs is subverted
- Wireless sensors are miniature, cheap, easy to install, and power-efficient nodes
  - Can be deployed densely (no scalability issues)
  - Able to self-configure to cope with failures in nodes
- WSNs are constituted by a huge number of nodes and thus provide enhanced coverage of the transportation infrastructure
  - Thus, achieves better traffic management decisions

Introduction (3/4)

- Wired sensor nodes

Inductive Loops



Microwave Radar

Video Camera

Introduction (4/4)

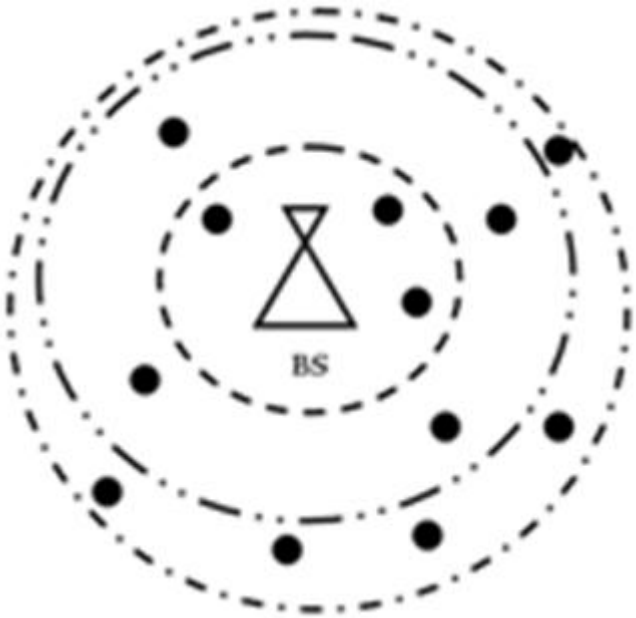
- Wireless sensor nodes

WSN Design Requirements

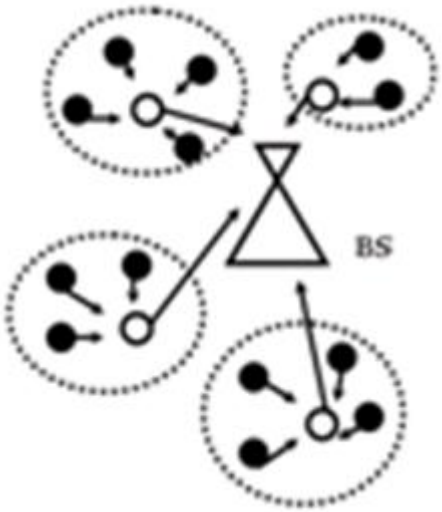
- Major design requirements for WSNs

1. Fault Tolerance: The disruptions in the services, due to nodes failures, should be minimized
2. Scalability: The size of the WSN affects the design of protocols at each layer (especially MAC and routing protocols)
3. Production Cost: The cost of a single sensor node should be minimized since the size of the WSN is huge
4. Network Topology: The deployment, maintenance, and modification of the topology should be handled appropriately to avoid degradations in the services
5. Security: nodes are usually deployed in hostile environments and communicate over a wireless medium. This makes the WSN prone to malicious attacks
6. QoS Support: Time-sensitive applications (like in military) require guarantees on QoS parameters
7. Power Consumption: Should be kept minimal to prolong the lifetime of the WSN

WSN Architectures



Layered Architecture



Clustered Architecture

WSN Architectures for ITSs (1/2)

- Two main categories:

1. Planar Architectures
   a. Single-tiered WSN architectures
   b. Infrastructure-less (P2P) communication paradigm is utilized for V2V
   c. Infrastructure-based communication paradigm for V2I
2. Multi-tired Architectures
   a. Two or more tiers constitute the WSN architecture
   b. Homogeneous Tiers vs. Heterogeneous Tiers
   c. Achieve enhanced performance

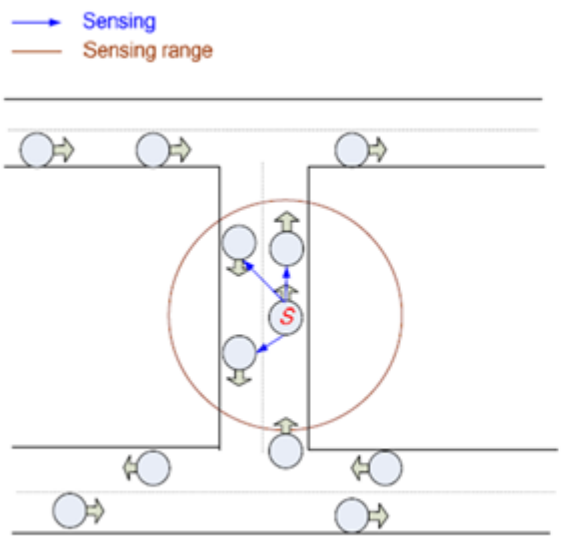
WSN Architectures for ITSs (2/2)

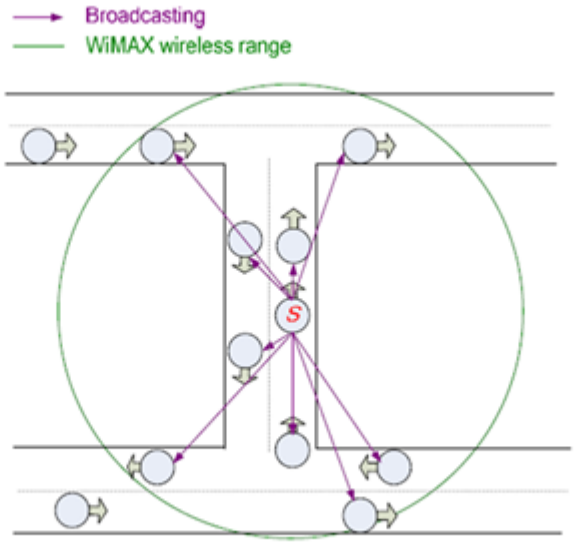
- Planar Architectures:
  1. WSN-based Navigation System in WiMAX networks
  2. Wireless Sensor Network for Intelligent Transportation Systems
  3. Clustered WSN for ITS
- Multi-tiered Architectures
  1. Sensor Network with Mobile Station
  2. Two-tiered WSN for Real-Time Communications
  3. Sensor Network-Based Traffic Information Service System

Planar Architectures (1/7)

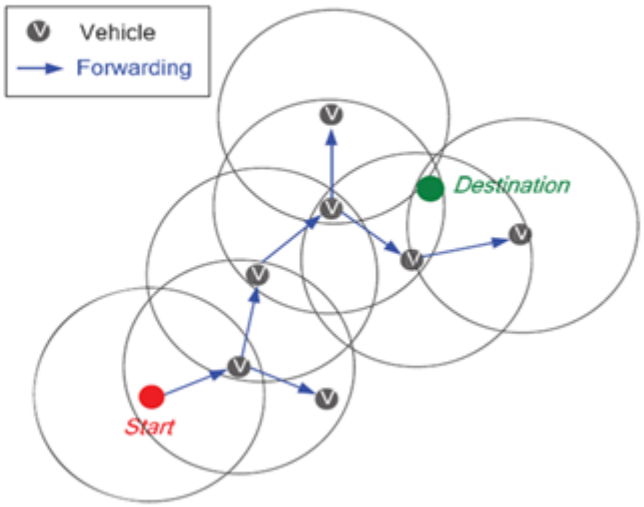
1. WSN-based Navigation System in WiMAX networks
   - Objective: determine the optimal route (i.e., most economic and least travel time) to a targeted destination
   - V2V communications paradigm is utilized (MANET)
   - Beside sensors, vehicles use IEEE 802.16 (WiMAX) network interfaces to broadcast info.
     - Provides a wide range of communication (3-5 km)
     - 30 Mbps data rate
     - Wider view of the roads
   - Vehicles are also equipped with GPS devices to get accurate location info.

Planar Architectures (2/7)





Sensing & broadcasting



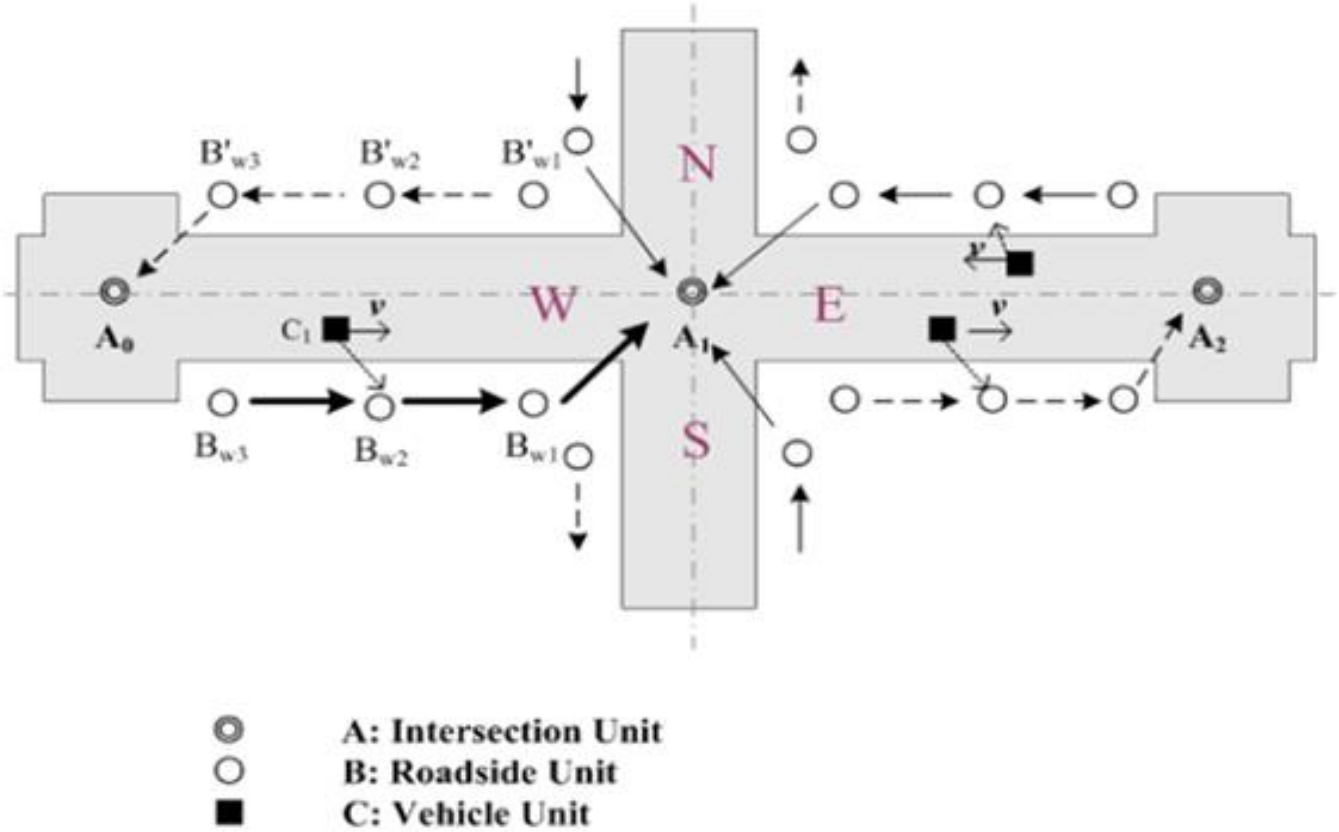
Inquiry about the traffic towards the destination

Planar Architectures (3/7)

2. WSN for ITSs (WITS)

- Objective: organize the traffic at road intersections
- Sensors on vehicles, roadside units (RSUs), and intersection units (IUs) (V2V and V2I)
- Data flows from vehicles to RSUs (for aggregation) that relay them to the IUs which finally send them to a strategy sub-system
- RSUs are installed on both sides of a road for fault tolerance purposes
- RSUs facilitate the localization problem as they are installed on pre-defined positions and relay data either upstream or downstream

Planar Architectures (4/7)

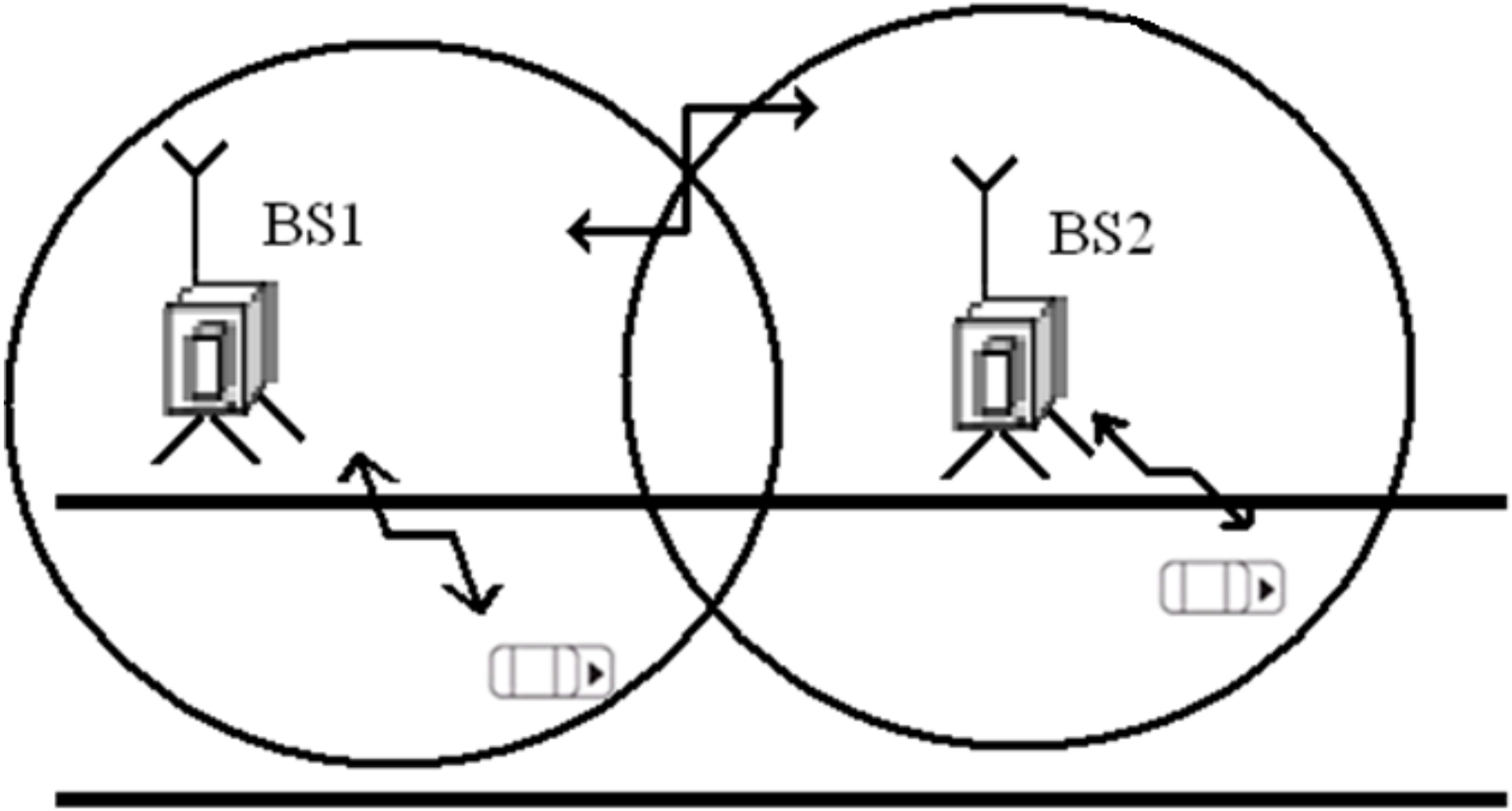


Planar Architectures (5/7)

3. Clustered WSN for ITS

- Objective: road traffic monitoring
- Clusters constituted by BSs (cluster heads) installed on the roadside and one or more passing by vehicles (cluster members)
- Data flow from vehicles to BSs (V2I), from BSs to vehicles (I2V) and among the BSs themselves
- Vehicles are equipped with sensors while the BSs comprise mass storage memories to store a large volume of information
- The existence of multiple BSs enables the WSN to tolerate faults

Planar Architectures (6/7)



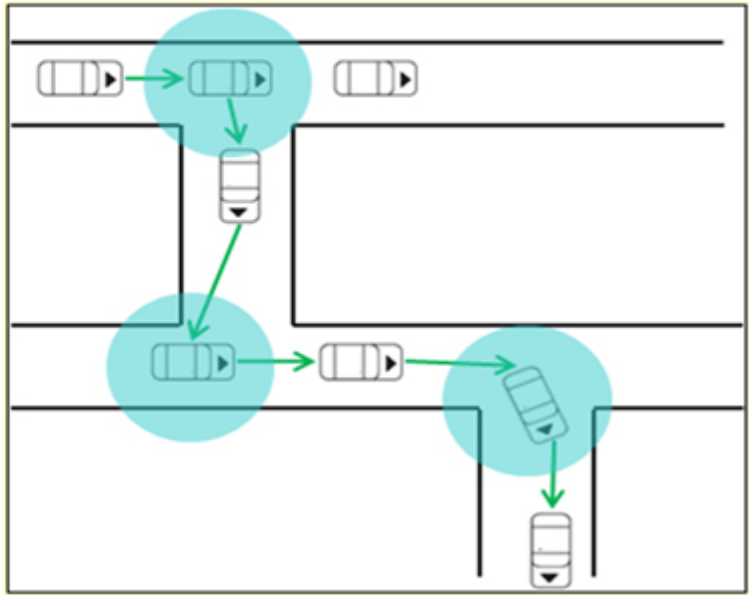
Planar Architectures (7/7)

- The three planar architectures use different methodologies, each addressing different problems
  - WNSW is infrastructure-less and depends solely on vehicles' sensors
    - ✓ No need for localization algorithms
    - ✓ Vehicle's battery as power source
    - ✓ No burden of installations and maintenance costs
  - WITS moves the burden of complex computations to the roadside and intersection sensors
    - Simplifies the tasks handled by the vehicles' sensors
  - The clustered WSN provides better fusion and aggregation of data before delivering them to the final decision-making stage

Multi-tiered Architectures (1/7)

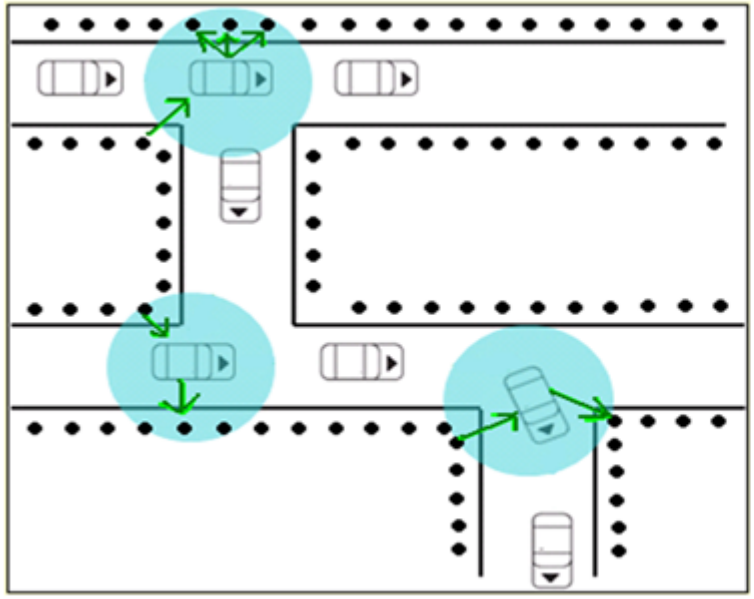
1. Sensor Network with Mobile Station (SNMS)
   - Objective: road traffic monitoring
   - Two tiers:
     - Lower tier: a single-hop network of RSUs and a single vehicle (I2V)
     - Upper tier: a P2P network of vehicles (V2V)
   - Lower tier: data are collected and aggregated by RSUs and transferred to the vehicles (sinks)
     - Bluetooth technology is used
   - Upper tier: Multi-hop ad hoc network

Multi-tiered Architectures (2/7)



Upper Tier

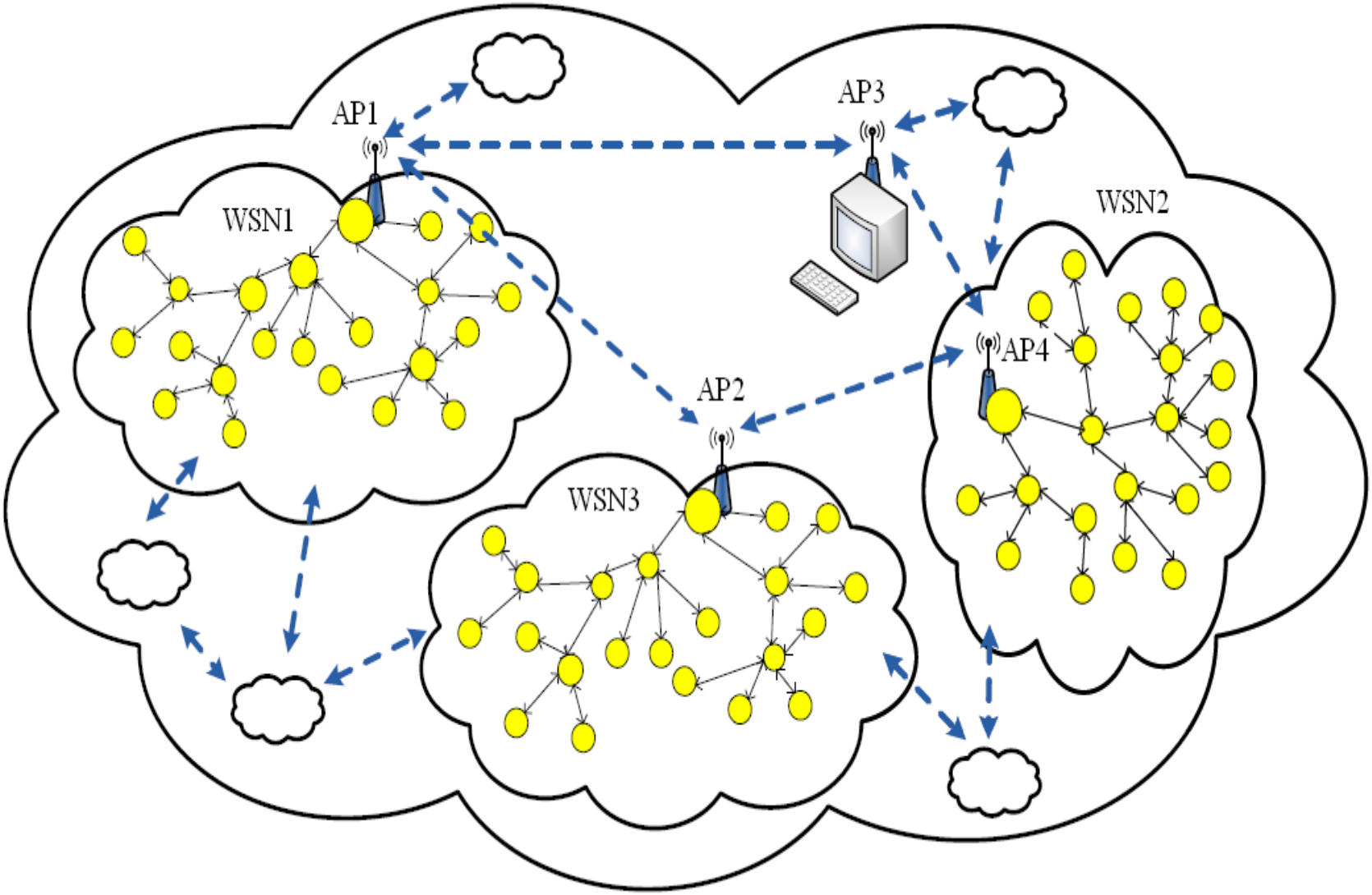
Lower Tier



Multi-tiered Architectures (3/7)

2. Two-tiered WSN for Real-Time Communications (TTW-RTC)
   - Objective: road traffic monitoring
   - Two tiers:
     - Lower tier: a WSN constituted by vehicles equipped with sensors (V2V)
       - IEEE 802.15.4 (ZigBee) is used
     - Upper tier: an overlay WLAN constituted by resourceful Access Points (APs)
       - IEEE 802.11 (WiFi) with the IEEE 802.11e extension
   - The upper tier copes with complex computations as it is more resourceful than the lower tier
     - Memory, power resources, range of coverage, and data rate

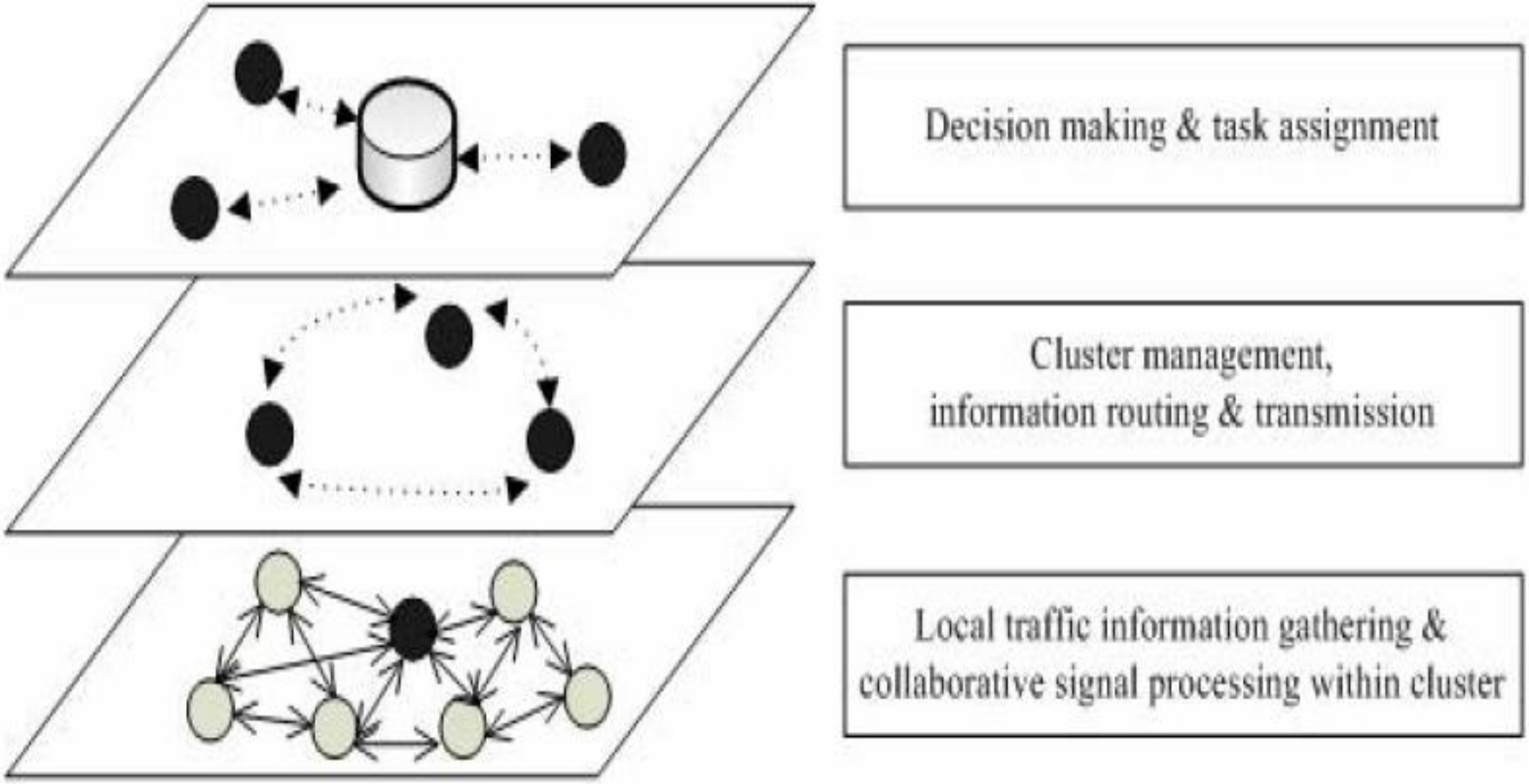
Multi-tiered Architectures (4/7)



Multi-tiered Architectures (5/7)

3. Sensor Network-Based Traffic Information Service System (SNTISS)
   - Objective: traffic information collection
   - Three-tiered clustered architecture
     - Lower tier: clusters of sensors for sensing fusing data
     - Middle tier: cluster-heads (or leaders) to handle management tasks beside transmitting data to terminals in the upper-tier
     - Upper tier: a mass data storage terminal that handles practical traffic control and service strategies (decision-making tier)

Multi-tiered Architectures (6/7)



Multi-tiered Architectures (7/7)

- The burden of complex computations is distributed over multiple tiers
- Provide better opportunities to support QoS
- The SNTISS architecture is preferred as it provides an accurate and generic framework and breaks down the tasks properly among the tiers

Future Research Directions

- Devise WSN-based architectures for ITSs that can provide more support to security
  - Security is a critical issue in WSNs in general
  - In ITSs, compromising a set of sensor nodes can be a mean to inject false data to provide travelers with wrong information about the conditions of the roads
  - Therefore, the services of the ITSs can face major degradations

Conclusion

- ITSs are a major area of application for WSNs
- WSNs achieve flexible and accurate ITSs as they are easy to install, cost-effective, densely deployed, and last for long periods
- WSN-based architectures for ITSs are categorized into planar and multi-tiered
- Multi-tiered architectures can alleviate the problems associated with the constraints in the WSNs (power, memory…etc) by incorporating different technologies and resources at different tiers

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QUESTIONS?