Ferry-Based Linear Wireless Sensor Networks

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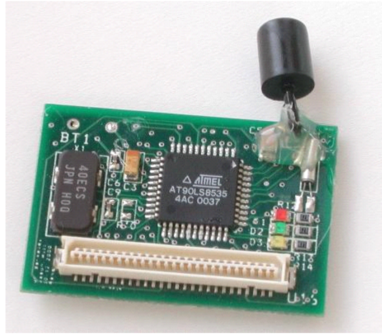
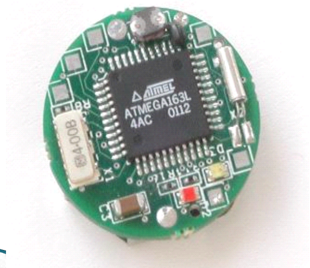
Outline

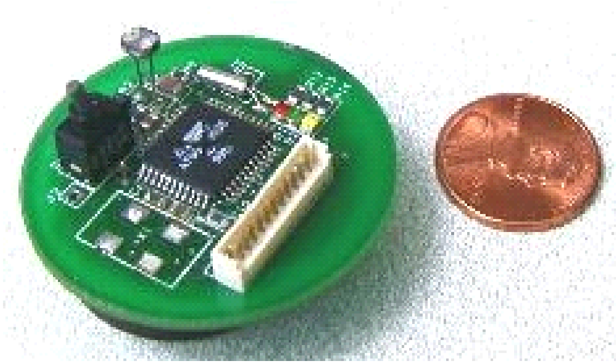
- Introduction: LSNs and FLSNs
- Network model
- Networking technology for various links
- Ferry movement algorithms
- Simulation results
- Conclusions and future research

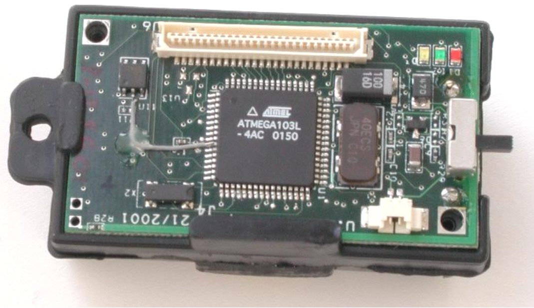
Wireless Sensor Networks

- Wireless sensor networks (WSN) advancements in technology
- Sensor networks application: environmental, military, agriculture, inventory control, healthcare, etc.









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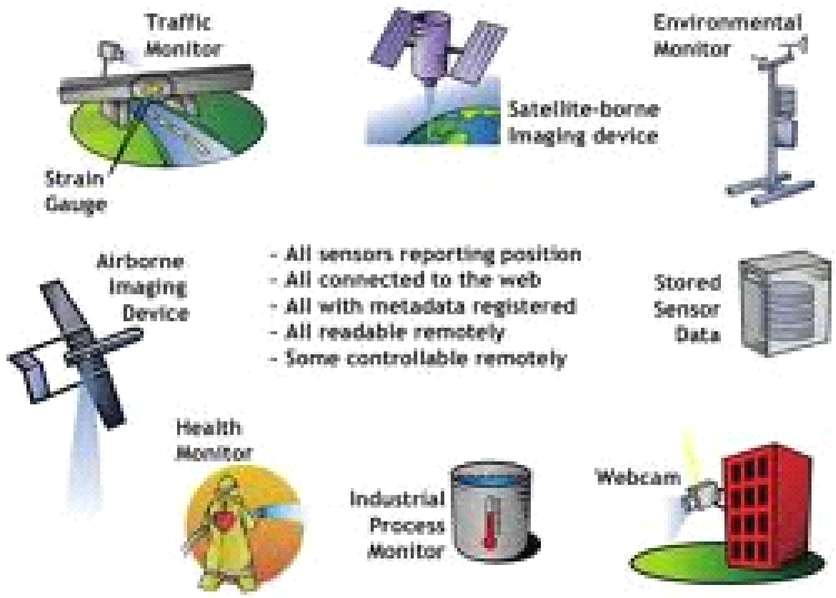
Applications of WSNs

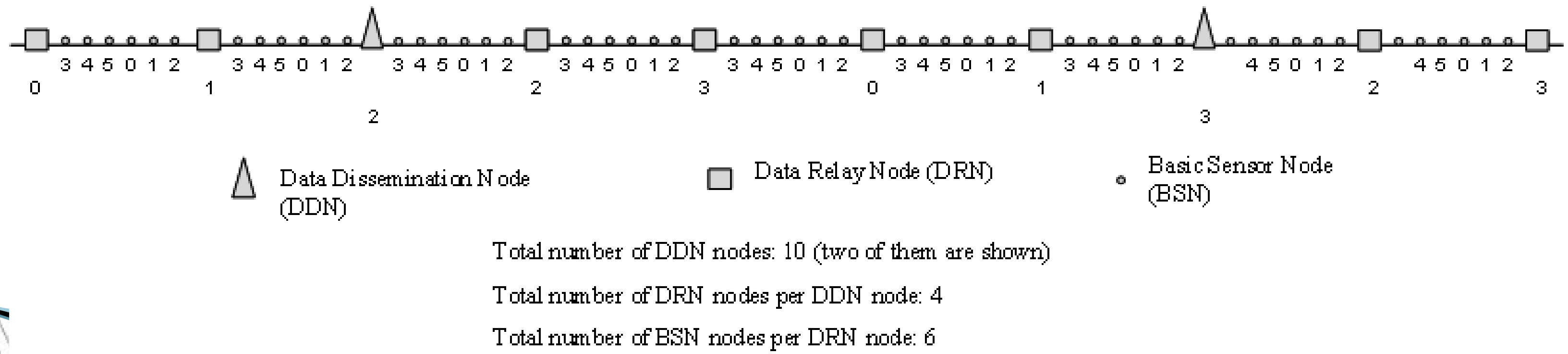
Applications for WSNs:

- Weather monitoring
- Security and tactical surveillance
- Fault detection and diagnosis in:
  - Machinery
  - Large bridges
  - Tall structures
- Detecting ambient conditions such as:
  - Temperature
  - Movement
  - Sound
  - Light
  - Radiation
  - Stress
  - Vibration
  - Smoke
  - Gases
  - impurities
- Presence of certain biological and chemical agents



Linear Sensor Networks

- Existing wireless sensor network research
- Assumption that the network used for sensors does not have a predetermined linear structure.
- Linear alignment of sensors can arise in many applications
- Linear characteristic can be utilized for enhancing the communication quality and reliability in the such systems
- We can design adapted protocols for this special kind of sensor networks.



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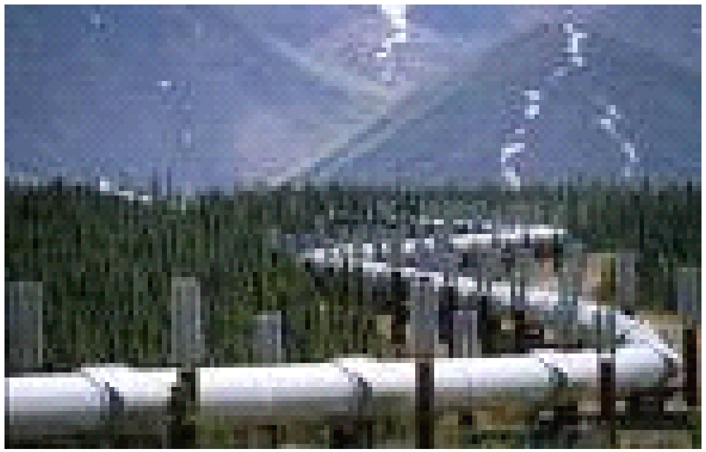
Applications of LSNs

- Monitoring and protection of oil, gas, and water pipeline infrastructure using wireless sensor networks.



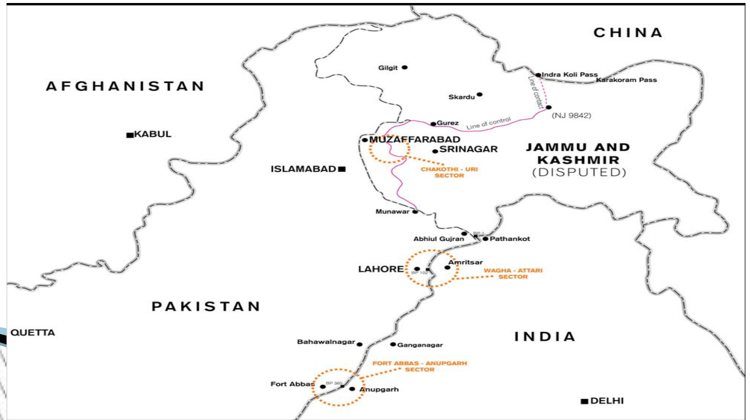
Oil, Gas, and Water Pipeline Use

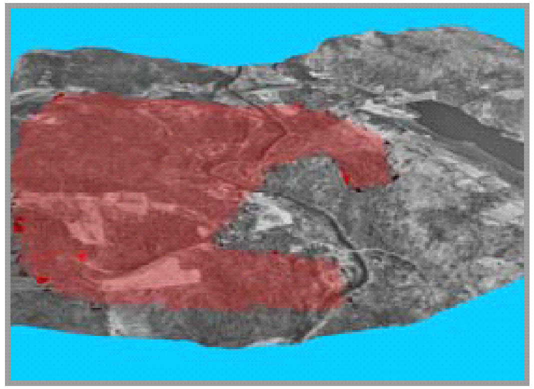
- UAE (2006):
  - 2,580 Km of gas pipelines
  - 2,950 Km of oil pipelines
  - 156 Km of refined products pipelines.
- Desalinated water.
- Saudi Arabia: 3,800 Km.

Use pipelines for transportation from plants to cities and populated areas.
Oil and gas industries heavily depend on pipelines for connecting shipping ports, refineries, and wells.
Types of pipelines: above ground, underground, under-water.

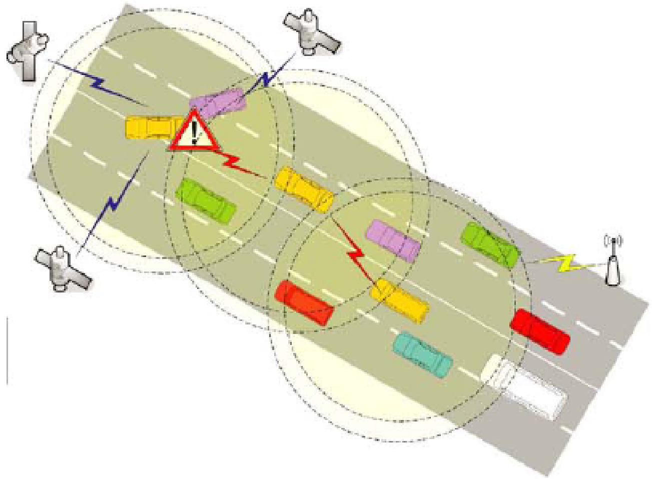
Border Monitoring

- Monitoring international borders for different activities.
- Illegal smuggling of goods, or drugs, unauthorized border crossings by civilian or military vehicles or persons, or any other kind of activities.
- Different deployment strategies.
- Deploy sensors by dropping them in a measured and controlled fashion from a low-flying airplane, installing them on a fence, etc.
- Resulting topology: linear sensor network with a relatively uniform node density distribution.





IVC Network and Railroad/subway monitoring



- **IVC Network**
- Roadside networks used to monitor vehicular activities.
- Vehicle-to-Vehicle (V2V) via infrastructure.
- Vehicles-to-Infrastructure (V2I) communication.
- Internet access of vehicles
- **Railroad/subway Monitoring**
- Sensors to monitor fatigue-critical components in structure of a railroad bridge.
- Sensors can monitor dynamic strains caused by the passing of trains.
- Other applications: River/sea cost monitoring, etc.

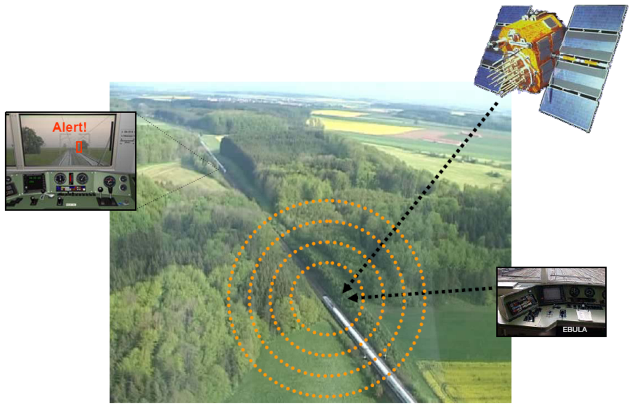
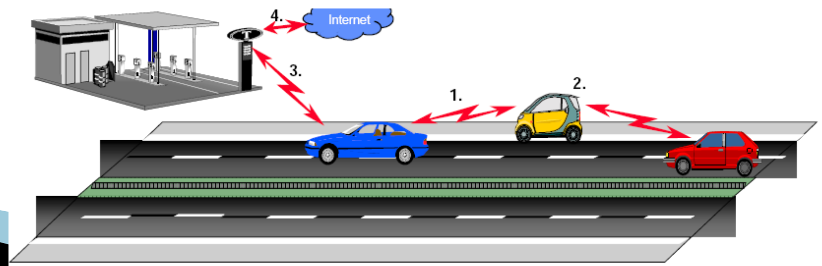


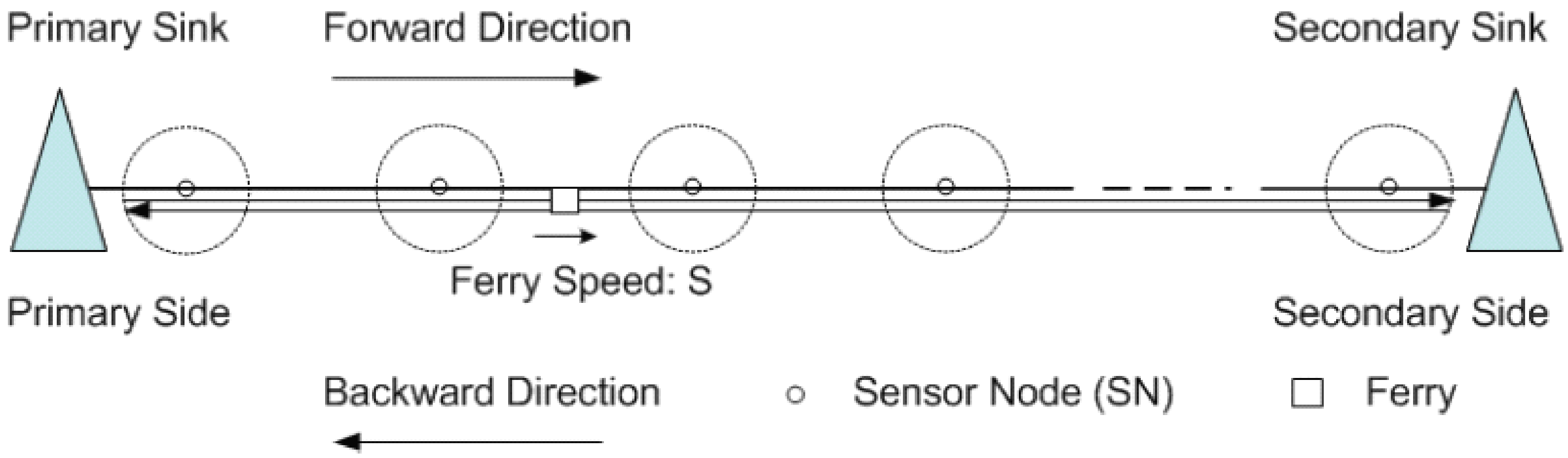
Fig. 1: Interaction of the components of RCAS



Why New Architectures and Protocols Are Needed ?

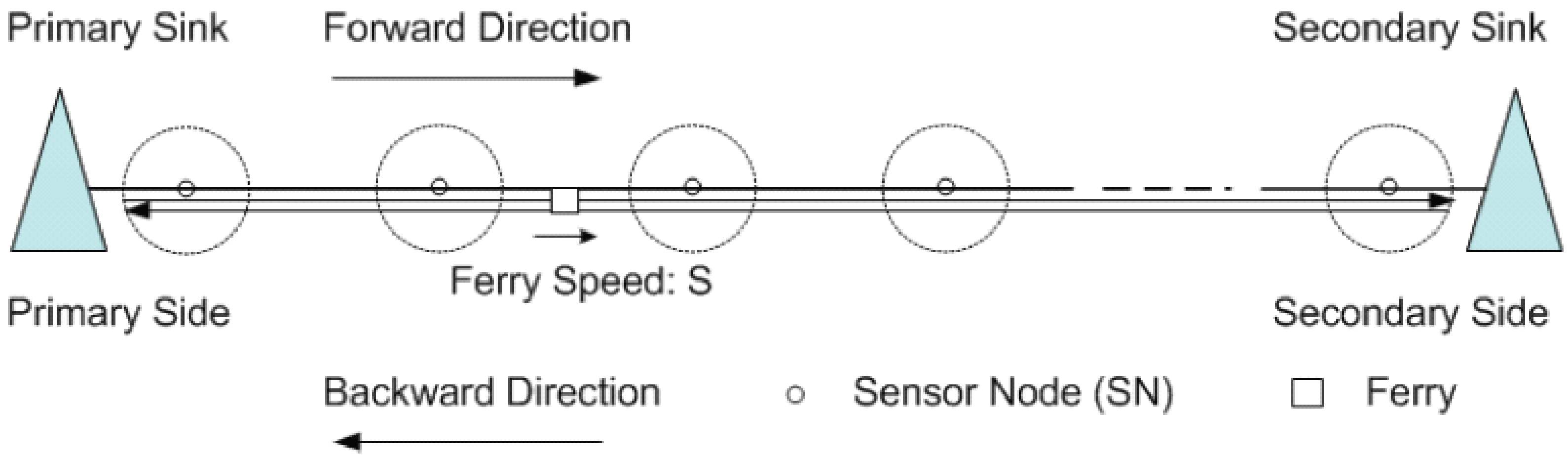
- **Increased routing efficiency**:
  - Take advantage linearity to significantly increase routing efficiency.
  - Multi-dimensional routing protocols would not very efficient.
  - Use flooding for route discovery and maintenance, which costs bandwidth, processing resources, delay.
  - Exploit linearity to eliminate or reduce route discovery.
- **Increased reliability**:
  - With multidimensional routing protocols: node failures => route discovery or costly local repair.
  - If no other alternative links are available, the connectivity of the network is compromised.
  - In LSNs specialized solutions to overcome node failure. E.g. extend transmission range. Easier with LSNs predictable structure.
  - Can use directional antenna technology in an efficient way to: increase range, reduce interference, avoid hidden terminal problems, and minimize power consumption.
- **Improved location management**:
  - Topology discovery can provide information about node location.
  - Network can easily, and precisely locate problems and take corrective measures.
  - Necessary for maintenance scheduling, surveillance, and quick emergency response.
- **LSN Classification**:
  - Thin and thick
  - Multiple types of nodes/hierarchy

FLSN System Architecture



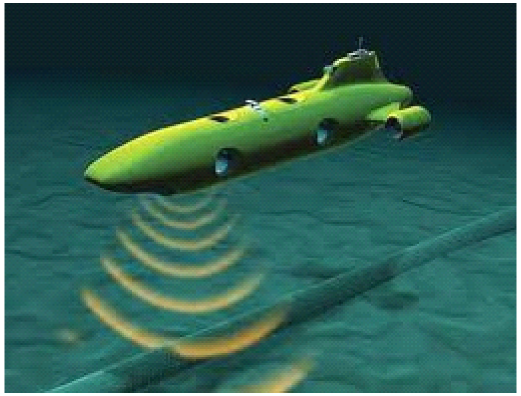
- Pure multihop approach costly in energy
- We introduce a framework for monitoring LSNs with data collection using ferries
- Three types of nodes: SN, ferry, and sink
- SNs transmit to the ferry which transports data to the sink

FLSN System Architecture – Advantages



- Distance between consecutive SNs not limited by communication range
- In multihop: add nodes, or increase range for connectivity
- Elimination of transmission interference and hidden terminal
- Solves the problem of disproportionate use of nodes near sink
- Ferry can perform functions such as data aggregation, scheduling, sensor operating system and software configuration/programming/updating, localization, and synchronization

Network Model



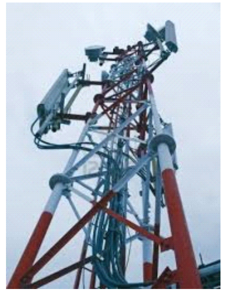
Sensor Node (SN):

- Basic sensing, placed at regular intervals

Ferry:

- More capable mobile node
- Can vary speed
- Type depends on application
- Can be an UAV, AUV, etc.

Sink:



Transmit to NCC

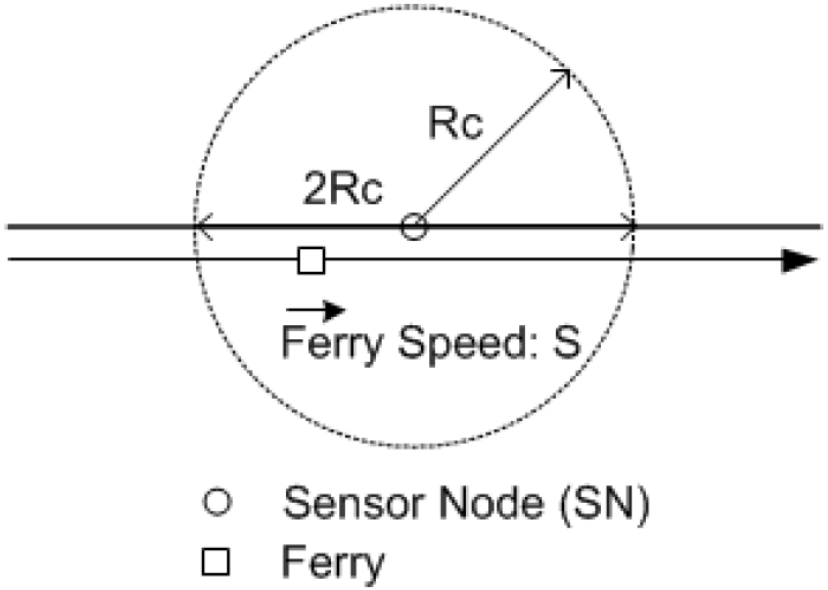
Uses Available technology in region (e.g. WiMAX, GPRS, cellular, etc.)

Multiple ferries/segments:

- reduce e2e data delivery delay
- Increased throughput (parallelism).
- Increased reliability

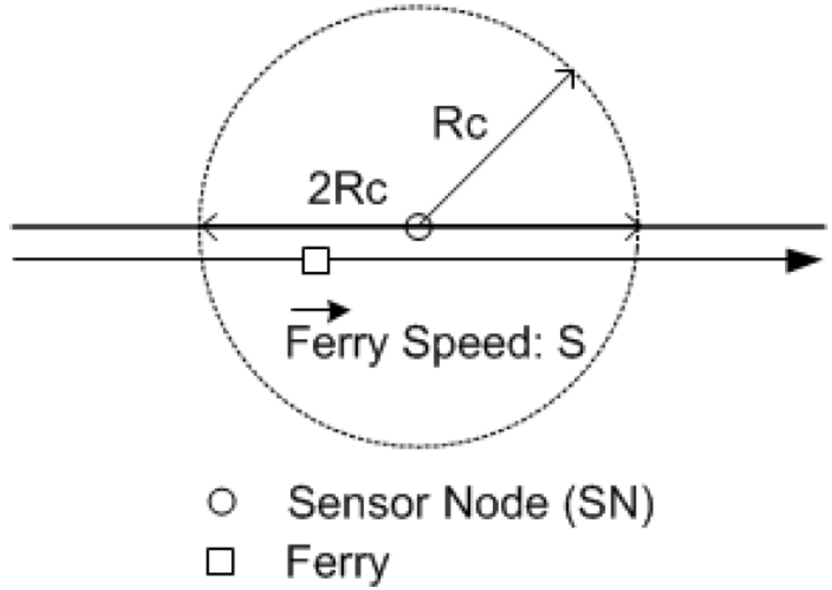
System Parameters

- n: This is the number of sensor nodes
- d: This the physical distance between each of two consecutive sensor nodes.
- L: The length of data which is exchanged with the ferry (in bytes).
- R: The bit rate for the communication between the SN and the ferry.
- R_s: This is the sensing range of a sensor node.
- R_c: The communication range of an SN.
- Message time-out value T
- Message delay: most significant delay value
- Two types of data traffic are considered:
  - Best effort (BE) traffic
  - Priority traffic

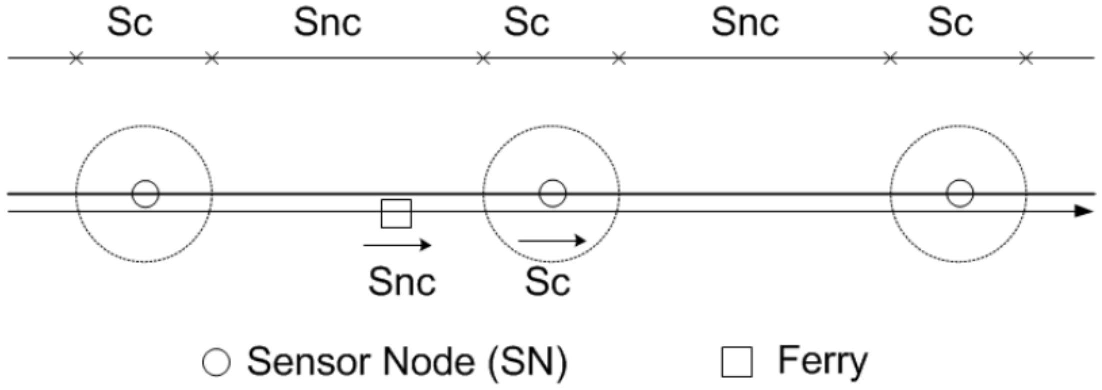


Ferry Mobility Protocols: Constant Speed Ferry (CSF) Algorithm

- Ferry moves between sinks at a constant speed, collecting data from SNs and delivering to the next sink:
  - Parameters:
    - Ferry speed:
    - Average Delay =
    - *Min Speed:*



Variable Speed Ferry (VSF) Algorithm

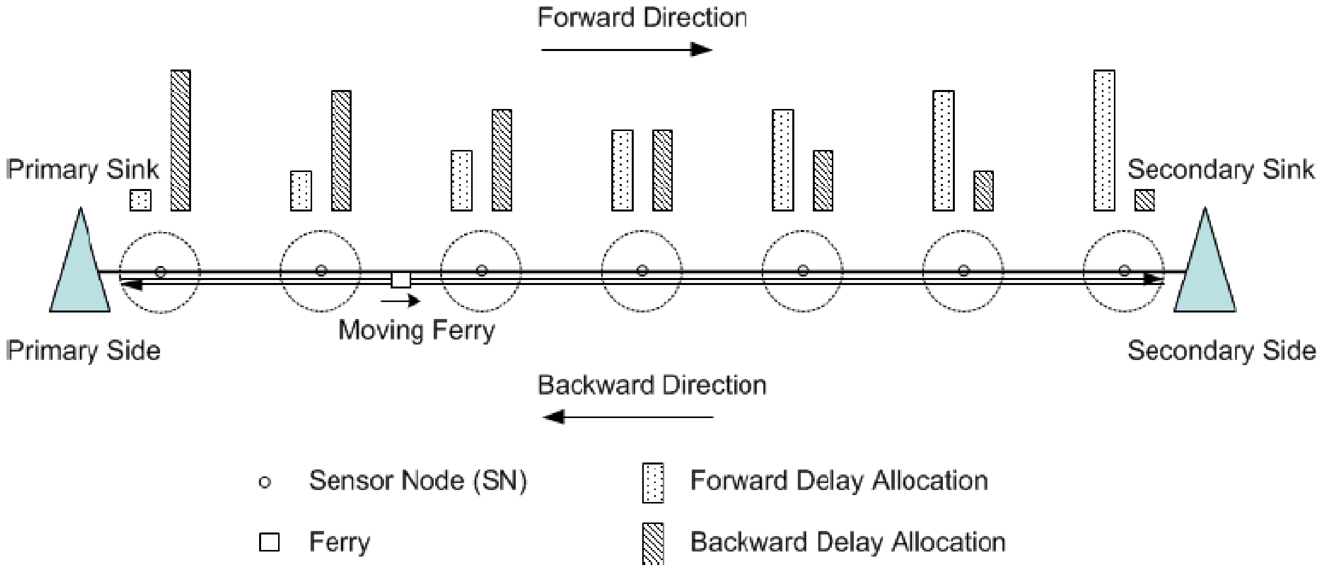


- Ferry moves in same way as CSF but with two speeds:
  - : Speed while in communication
  - : Speed while in no communication (between SNs). Usually by ferry speed limitations.
- Average delay: +
- Buffer of ferry: =

Adaptable Speed Ferry (ASF) Algorithm

- For some applications: message arrival rate at the SNs is variable.
- Quality and/or quality of data collection can increase with emergency or special situations (special audio/video capabilities, turned ON as needed. Response to certain events, intruder detection, high temperature, pressure, or vibration in a pipeline, etc.) – Can use push or pull.
- In ASF, Ferry speed while in communication is determined by the amount of data in the SN buffer:
  - s_c: variable (depends on SN buffer size)
  - s_{nc}: constant
- In CSF and VSF algorithms, delay is bounded.
- In ASF, delay is un-bounded – Large data in an SN can slow down ferry in a detrimental fashion.
- To bound delay: delay allocation strategy is used.

Adaptable Speed Ferry Algorithm – Cont'd



Delay allocation strategy favor collecting **less data from far SNs** and **more data from close SNs** to the **destination sink** in order to reduce total end-to-end delay.

Adaptable Speed Ferry Algorithm (ARF)

Algorithm 1 ASF-DA Algorithm - Delay Quota Initialization

/* Set total delay quota for node i according to its position. T_q is a basic quantum (or unit) delay parameter that is set depending on the application.*/
for i = 1 to n **do**
  if $dir = forward$ **then**
    $D_i^t = i * T_q$
  else
    $D_i^t = (n - i + 1) * T_q$
  end if
end for

- Node contains two buffers: BE and priority.
- We use variable λ to allocate: λ = 0.8 => 80% quota for priority traffic.

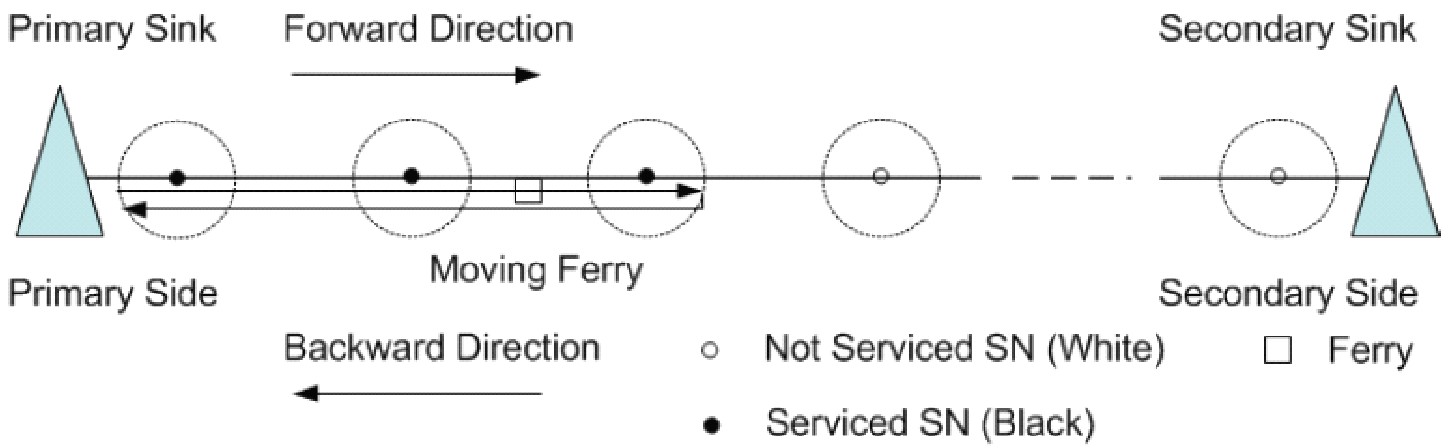
Algorithm 2 ASF-DA Algorithm - Ferry/SN Data Exchange

if $(D_i^t * R) \geq B_i^t$ **then**
  /* Allocated delay quota is more than the time required to download the buffer of SN i. So calculate the *actual delay* time to download the current buffer of node i */
  $D_i^a = B_i^t \,/\, R$
  /* Set the ferry speed to download all data at SN i */
  $s_{ci} = 2 * R_c \,/\, D_i^a$
  /* Calculate the remaining delay */
  $D_i^r = D_i^t - D_i^a$
  /* Distribute the remaining delay quota to the rest of the SNs between this SN and the destination sink */
  $distributeRemainingDelay(dir, i, D_i^r)$
else
  /* Allocated delay quota is less than or equal to the time required to download all. So set ferry speed according to delay quota. */
  $s_{ci} = 2 * R_c \,/\, D_i^t$
  /* Set the actual delay equal to the total delay quota */
  $D_i^a = D_i^t$
end if
/* Download the data using the calculated *actual delay* */
$downloadDataFromCurNode(i, D_i^a, \lambda)$

Algorithm 3 Download While Ferry is in Communication Range Function: $downloadDataFromCurNode(i, delay, \lambda)$

/* Total downloadable priority traffic size at SN i (in bytes): */
$B_i^p = R * Delay * \lambda/8$
Download B_i^p bytes from priority data buffer of i.
/* Total downloadable BE traffic size at SN i (in bytes): */
$B_i^b = R * Delay * (1-\lambda)/8$
Download B_i^b bytes from BE data buffer of i.

Adaptable Routing Ferry (ARF) Algorithm



- Also for variable message arrival rate
- Ferry moves from primary sink to secondary at *NORMAL_SPEED* using *NORMAL_MODE*.
- Continues till ferry buffer reaches a critical threshold .
- Then ferry switches to *GO_FAST_TO_NEAREST_SINK* mode at *FERRY_MAX_SPEED*.
- At sink download and turn around and go fast past serviced SNs to un-serviced SNs, then resume *NORMAL_SPEED* *(Flag used: white/black)*
- Objective: minimize delay by making the ferry deliver data fast when a threshold is reached (threshold: application-dependent).
- Provide fairness in servicing SNs, and prevent SN starvation.

Adaptable Speed Ferry (ARF) Algorithm – Cont'd

Algorithm 4 ARF Algorithm - Initialization When Ferry Starts in the Direction of the Opposite Sink

```
/* Initialization of F_tip flag */
if blackNodeCounter = n then
   for (i=1; i ≤ n; i++) do
      blackNodeCounter = 0
      F^i_tip = WHITE
   end for
end if
/* Current node variable initialization */
if (networkStartup = TRUE) OR (dir = FORWARD) then
   cn = 1
else
   cn = n
end if
ferryMode = NORMAL_MODE
ferrySpeed = NORMAL_SPEED
```

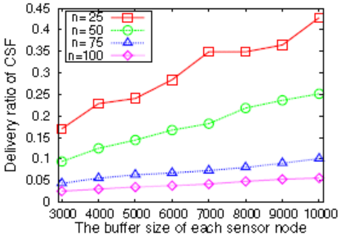
Algorithm 5 ARF Algorithm - Ferry Algorithm at an Intermediate SN

```
Let i be the ID of the current node
Let F^i_sit be serviced-in-this-pass flag. F^i_sit is set to BLACK
when node i is serviced in the current pass and set to WHITE
otherwise.
/* calculate the total download time for node i */
D^t_i = 2*R_c/ferrySpeed
downloadDataFromCurNode(i, D^t_i, λ )
if F^i_sit = WHITE then
   if curFerryBufferSize ≥ ρ then
      dir = getDirToNearestSink()
      ferrySpeed = FERRY_MAX_SPEED
      ferryMode = GO_FAST_TO_NEAREST_SINK
   end if
   /* Indicate that this node has been serviced in the current pass */
   F^i_sit = BLACK
   blackNodeCounter = blackNodeCounter + 1
end if
i = getNextNodeInDir(i, dir)
Go to i node at the current ferrySpeed
```

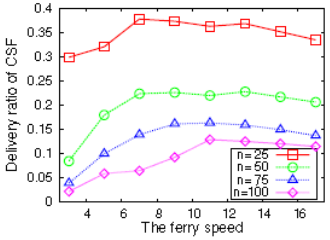
Simulation

- Evaluates the performance of the proposed algorithms, providing insights into the impact of various parameters.
- Parameters are mainly used to verify the operation (proof of concept) and study the performance of the algorithms.
- Parameters can vary considerably depending on application used.
- The performance metrics used in our evaluations:
  - The delivery ratio is the **ratio of the successful packets** received by two sinks to the overall packets generated by all SNs.
  - The average delay is the **average delay** experienced by the successful packets.

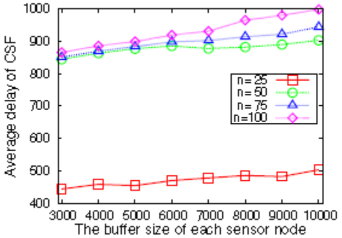
Simulation Results



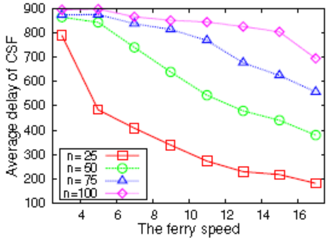
(a) Buffer size vs. delivery ratio



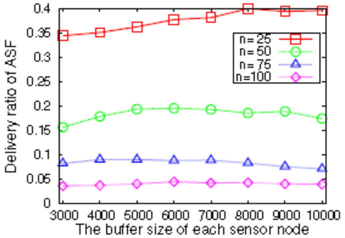
(b) Ferry speed vs. delivery ratio



(c) Buffer size vs. average delay



(d) Ferry speed vs. average delay



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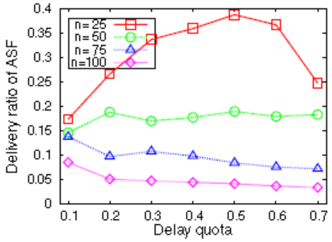
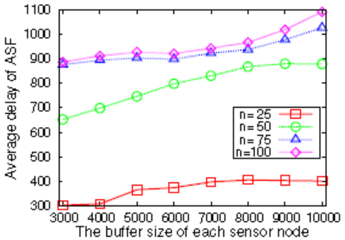
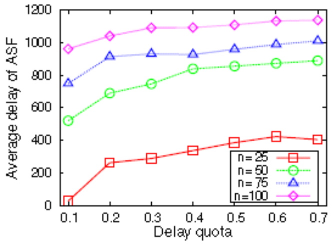


(b) Delay quota vs. delivery ratio



(c) Buffer size vs. average delay



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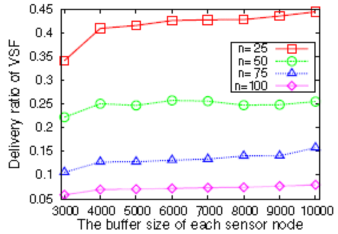
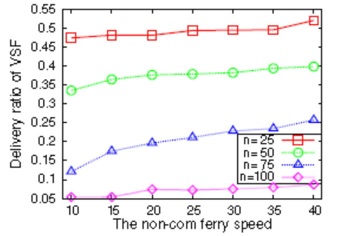
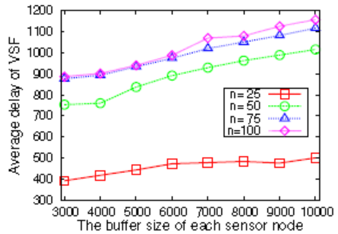


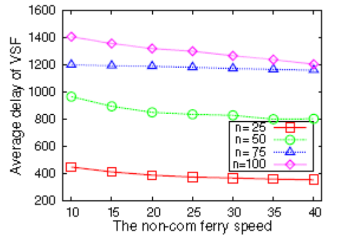
(a) Buffer size vs. delivery ratio



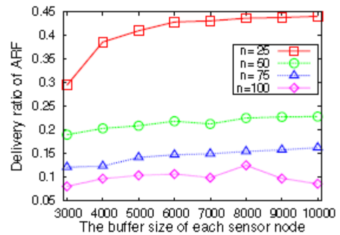
(b) Non-com Ferry speed vs. delivery ratio



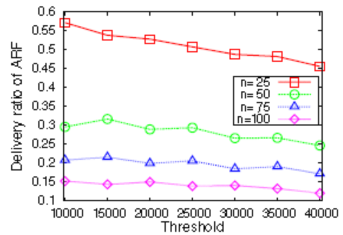
(c) Buffer size vs. average delay



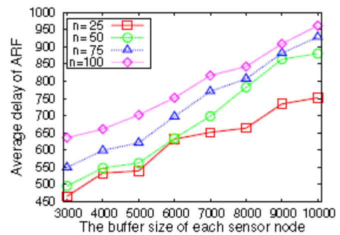
(d) Non-com Ferry speed vs. average delay



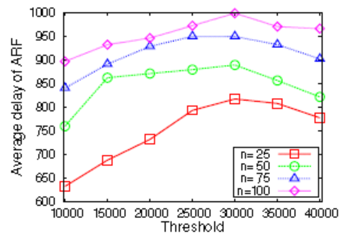
(a) Buffer size vs. delivery ratio



(b) Buffer threshold vs. delivery ratio



(c) Buffer size vs. average delay



(d) Buffer threshold vs. average delay

Summary of Results

- When SN buffer size increases, delivery ratio increases for all algorithms.
- When SN buffer size increases, average delay increases for all algorithms.
- The ferry speed, the non-com ferry speed in VSF, the delay quota in ASF, and the buffer threshold in ARF should be chosen carefully, and it may take time to find optimal values for a particular environment.
- When the time-out value increases, all algorithms perform better in terms of delivery ratio, and the average delay increases.
- There may exist some critical time-out values, related to the length of the time required for a ferry to travel from one sink to another.
- Some challenges remain. Objective is introduction of FLSN framework with various strategies for data collection.
- Simulation intended to provides some guidelines for future delay-tolerant data collecting systems.

Conclusions and Future Work

- Motivated and presented FLSN framework for data collection in LSNs using mobile ferry.
- Offered four possible ferry movement strategies.
- Basic simulation experiments performed to study the effect of different design parameters on network performance
- Ferry speed in and out of communication and other design parameters should be chosen carefully for a particular environmental setting
- Provides a foundation for future research to further expand and tailor design depending on the application.
- Future research can focus on: multiple ferries per segment, and algorithms for optimal ferry routes for certain data traffic distribution, optimal density and placement of various nodes/sinks to meet design constraints
- Objectives such as increased system reliability, performance, and reduced energy consumption in different type of nodes.

Thank you

Questions?