Assessing the Dependability of Sensor Network Information

Quality of Information (QoI) in Sensor Networks

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Problem Being Addressed

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- **How much confidence can one place on information from a sensor network?**
- **Military sensor networks are notorious for false-positives and false-negatives**
  - **Hastily deployed**
    - Sub-optimal sensor placement
    - Imprecise knowledge of sensor locations
  - **Adverse and unpredictable operating environments**
    - Compromised sensors
  - **Long-lived networks**
    - Sensors going out of calibration
    - Accumulated errors in data fusion
    - Degraded operations as batteries run out
  - **Detection algorithms tuned to decrease false-negatives**
- **All information must be considered actionable**
  - **No indication of the quality of the information (QoI)**

Project Objective

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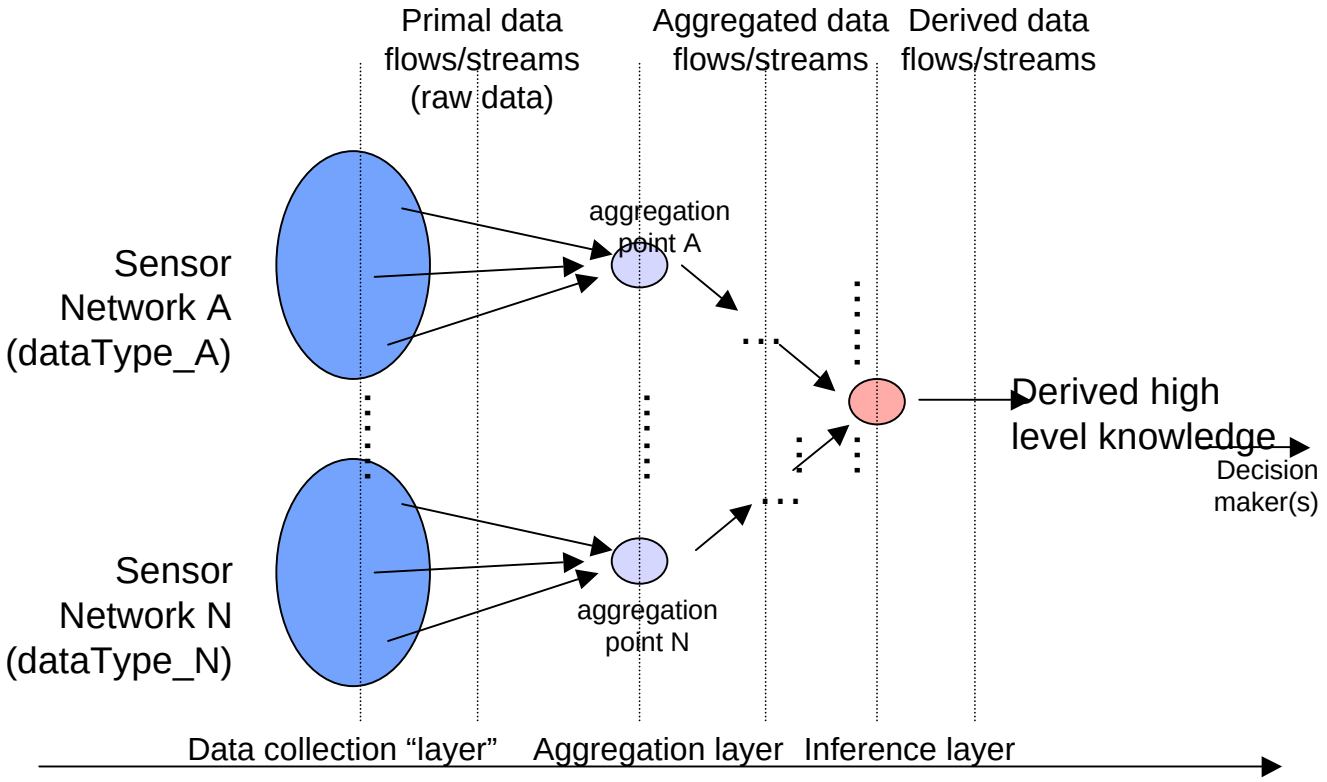
- **Framework to describe, analyze and estimate the QoI delivered by a sensor network**
  - **Define QoI and mechanisms to describe QoI**
  - **Understand how QoI changes as it is collected, aggregated and transmitted at various logical levels**



QoI in Sensor Networks

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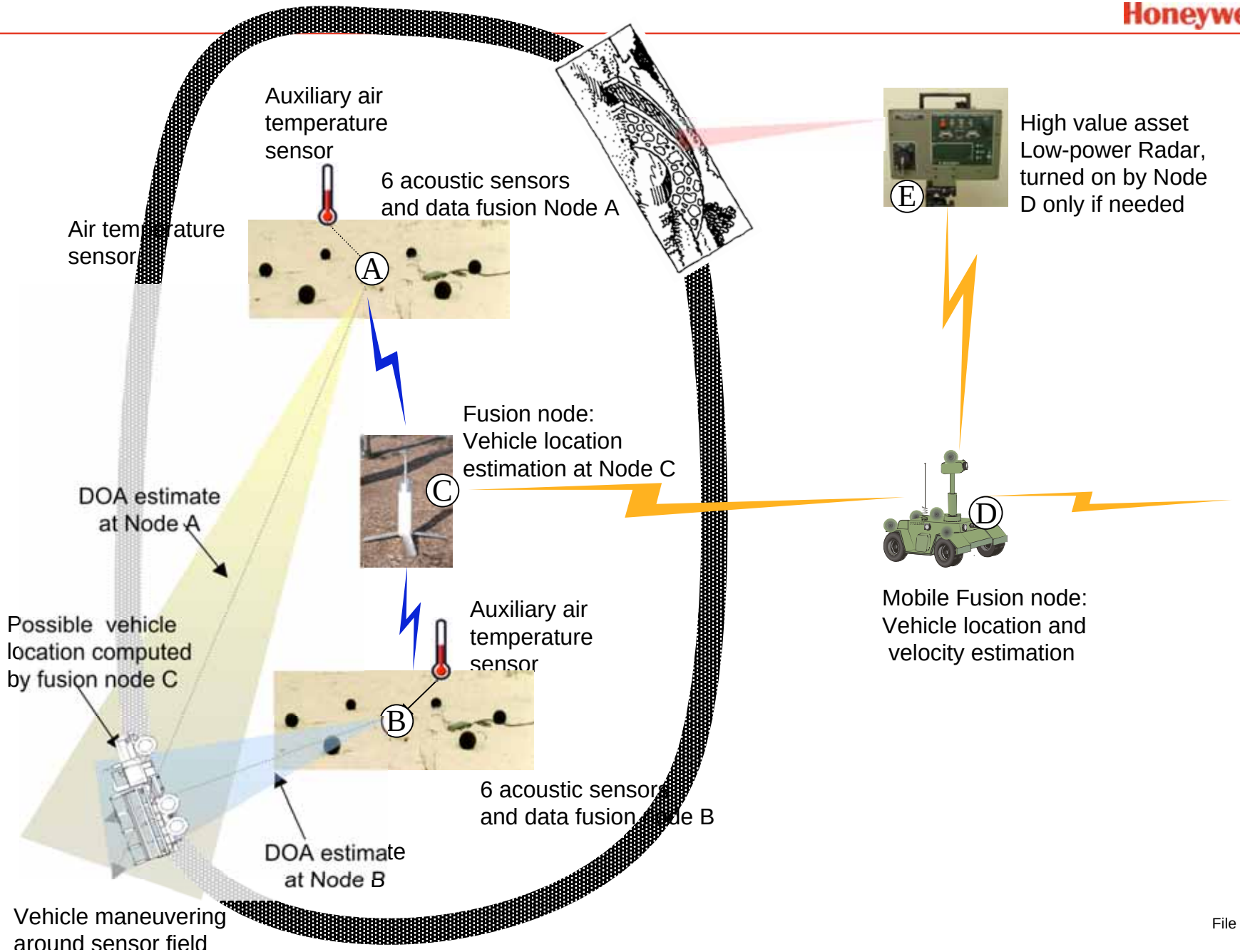
- **Measure of how well a particular body of information conveys the true state of the world, modeled at a particular level of abstraction**
  - **Quality is different from Value**

- **QoI computation**
  - **Based on meta-data that describes the information flowing through the sensor network**
    - Meta-data attribute selection based on model of the real-world
    - Meta-data attributes represent key dimensions of the model

QoI Illustrated



Data and Meta-Data Flows

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Information:
Waveform
Meta-data:
Time: 10:25:54
Sampling rate: 1024
Array: 6 element, Circular
Location survey error: 39.45, 46

A

Information:
Bearing (direction of arrival)
Meta-data:
Time: 10:25:54
No. Targets: 4
DOAs: #1 - 33°; #2 - 235°; #3 - 71°; #4 - 315°
Error: #1 – 1.5°; #2 – 2°; #3 – 2.5°; #4 – 4°

Information:
Temperature
Meta-data:
Time: 10:25:54
Temp: 28°C
Error: ±1

Information:
Vehicle location
Meta-data:
Time: 10:25:54
Location x = [53, -65, 20, 80]
y = [10, -18, 70, -20]
Error: Δx, Δy =[±2, ±3, ±5, ±7]

C

D

Information:
Vehicle location
Vehicle velocity
Meta-data:
Time: 10:25:54
Location x = [53.9]
y = [9.6]
Error: Δx, Δy =[±0.5]

Information:
Temperature
Meta-data:
Time: 10:25:54
Temp: 28°C
Error: ±1

B

Information:
Bearing (direction of arrival)
Meta-data:
Time: 10:25:54
No. Targets: 4
DOAs: #1 - 145°; #2 - 195°; #3 - 123°; #4 - 210°
Error: #1 – 1.5°; #2 – 2°; #3 – 2.5°; #4 – 4°

Information:
Vehicle distance & direction
Meta-data:
Time : 10:25:54
No. targets: 1
Range: 20
Velocity: 0.5m/sec
Error: ±1m, 0.01m/s
Long & Lat: 40.2, 46.5

Background

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- **UK Ministry of Defense and US Army Research Labs International Technology Alliance in Network Sciences**
- **Project is one of dozen being conducted by an IBM-led consortium**
  - **US and UK academia and research labs**

Project Activities

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- **Project structured around understanding contributors to QoI and their inter-relationships**
- **Contributors to QoI**
  - **Sensor characteristics and integrity**
    - Resolution, drift, calibration, etc.
  - **Sensor trustworthiness**
    - Attacks on the sensing channel
  - **Data fusion**
    - Fusion architecture. Lossy? Time consuming?
  - **Sensor network attributes**
    - Routing, power management, time synchronization
  - **Others, especially for non physics-based sensors (human intelligence)**
    - To be investigated over the course of the project

QoI Representation and Analysis Framework

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- Definition of QoI for sensor networks
- Framework the supports expression and computation of QoI
  - Extensions to SensorML?
  - Ontology to describe QoI attributes
  - Representation of the model against which QoI is being assessed
- Test using realistic applications
- Primary researchers
  - Chatschik Bisdikian (IBM)
  - Erol Gelebe (Imperial)
  - Jim Richardson & Vic Thomas (Honeywell)
  - Mani Srivastava (UCLA)
  - Raju Damarla and Tien Pham (ARL)

Possible Meta-Data For Temperature Sensor

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```
<capabilities>
 <PropertyList>
  <property name="measurementProperties">
   <MeasurementCapabilities>
    <measureResolution>
     <swe:Quantity definition="~:temperature" uom="~:degreeCelsius">0.1
     </swe:Quantity>
    </measureResolution>
    <dynamicRange>
     <swe:QuantityRange definition="~:temperature" uom="~:degreeCelsius">-45 60
     </swe:QuantityRange>
    </dynamicRange>
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     <swe:QuantityRange definition="~:accuracy" uom="~:percent">-0.5 0.5
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    </accuracy>
   </MeasurementCapabilities>
  </property>
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    <limit name="windSpeedLimits">
     <swe:QuantityRange definition="~:windSpeed" uom="~:metersPerSecond">0 175
     </swe:QuantityRange>
    </limit>
   </Limits>
  </property>
 </PropertyList>
</capabilities>
```

QoI and Sensor Network Services

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- **Year 1 focus on routing algorithms**
  - **Effect of routing schemes on QoI attributes and network performance**
    - Delays, energy consumption
  - **Bounds on routing algorithm performance**
- **Years 2 and 3: Effects of time-synchronization and localization accuracies on QoI**
- **Primary researchers**
  - **Erol Gelenbe (Imperial)**
  - **Mani Srivastava (UCLA)**
  - **Yunjung Yi and Vic Thomas (Honeywell)**
  - **Ping Ji (CUNY)**

QoI and Select Routing Parameters

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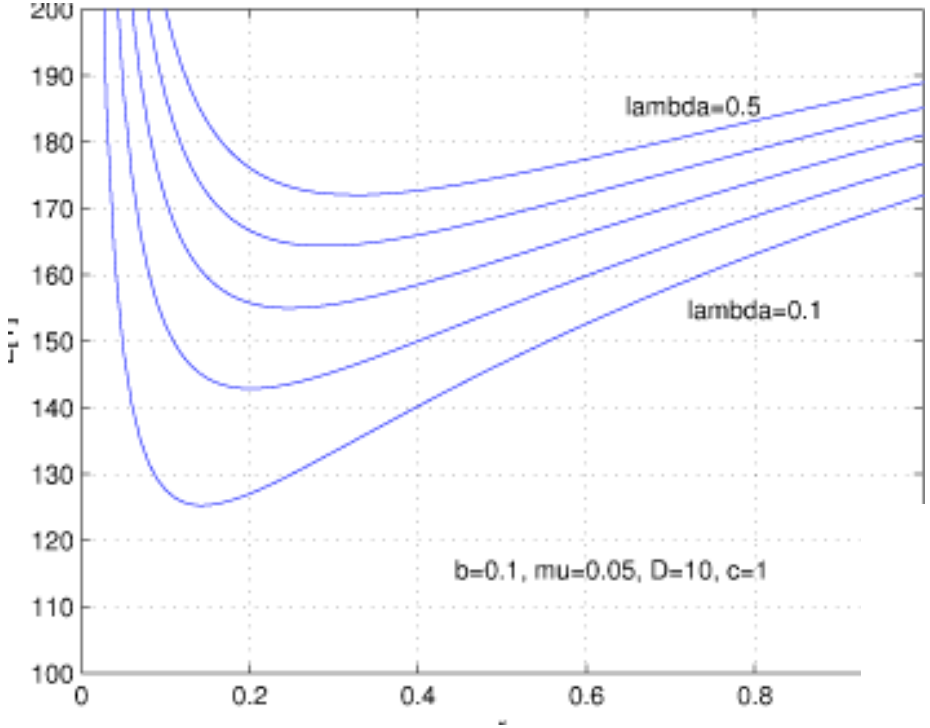
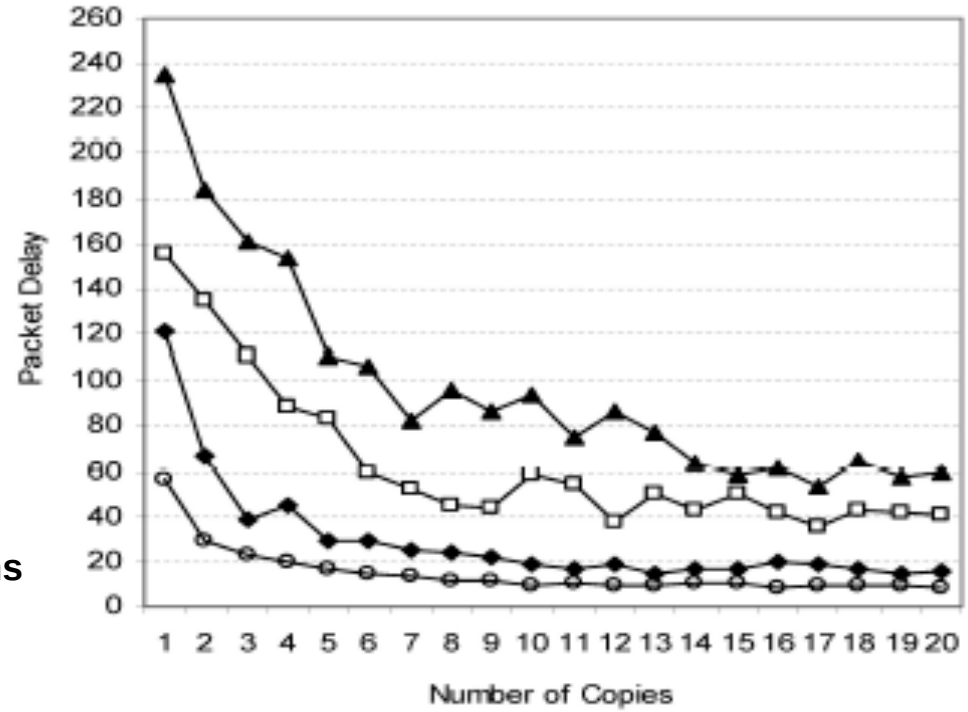


Timeliness vs. Packet Loss Rate



Timeliness vs. Redundant Transmissions

QoI and Sensor Characteristics

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- **Effects of sensors on QoI**
- **Characterized and modeled sensor faults**
  - **Offset faults: Calibration offset, spatial movement, sampling time shift**
    - $f(t) = \beta 0(t) + \gamma(t) + \varepsilon(t)$ with probability c
    - $f(t) = \gamma(t) + \varepsilon(t)$ with probability 1-c
  - **Gain faults: Calibration gain error**
    - $f(t) = \beta 1(t) + \gamma(t) + \varepsilon(t)$ with probability c
  - **Variance degradation faults: Aging of sensors, variance of ε(t) increases over time**
    - $f(t) = \gamma(t) + N(0, \sigma(t)2)$ with probability c
  - **Stuck-at-faults: Electrical or mechanical problems, obstructions etc.**
    - $f(t) = \beta 0(t)$ with probability c
- **Developing techniques to detect and compensate for such faults**
  - **Univariate and multivariate techniques**
- **Primary researchers**
  - **Mani Srivastava (UCLA)**
  - **Dinkar Mylaraswamy (Honeywell)**
  - **Robert Young (DSTL)**

Concluding Remarks

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- QoI in sensor networks different from QoI notions in databases, web searches, etc.
- QoI research can provide a scientific basis for the design, deployment and operation of sensor networks
  - Other projects looking at using QoI to address re-deployment