Resource-Efficient Encoding Communication and Fusion in Wireless Networks of Sensors and Actuators

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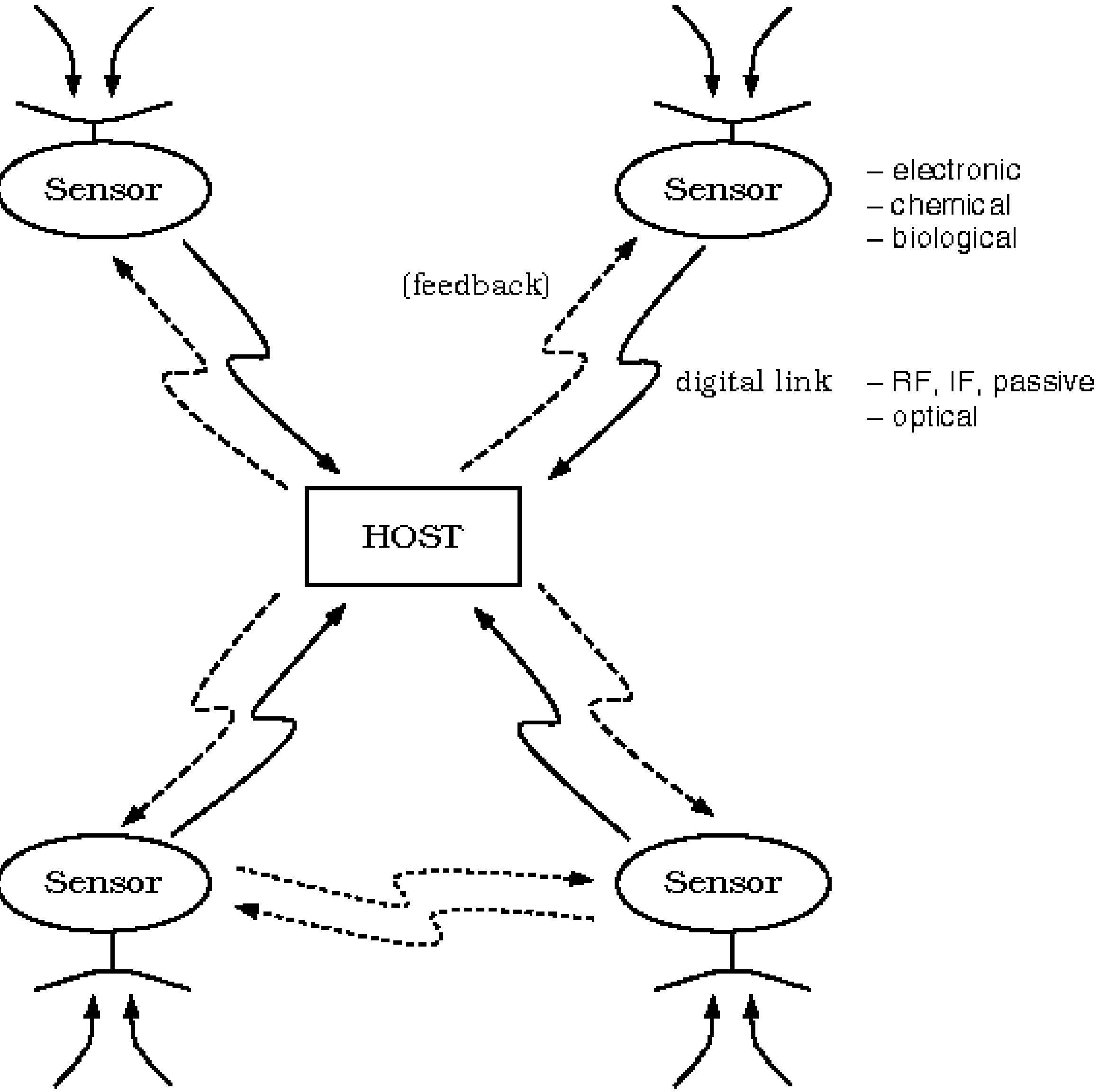
Wireless Sensor Networks



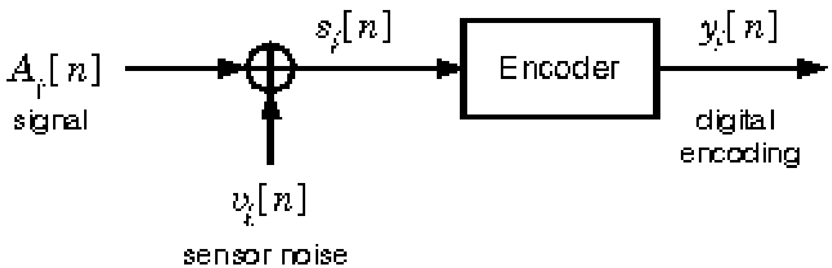
Sensor networks for

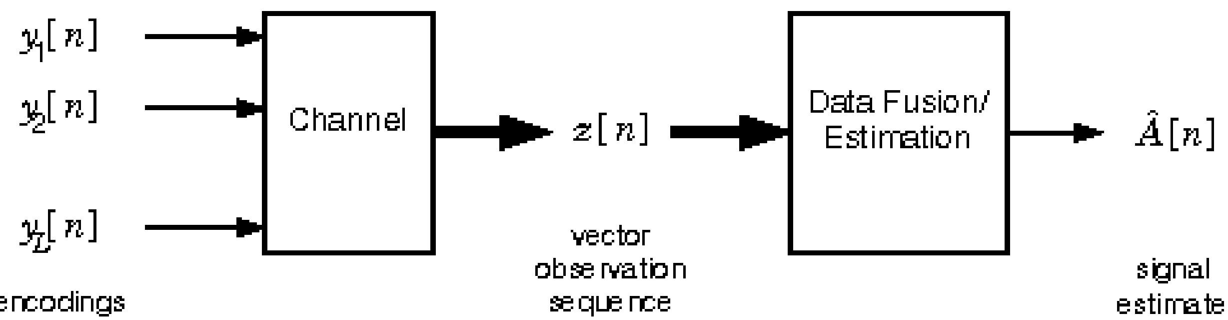
- surveillance and monitoring
- chemical/biological hazard detection
- earth observation
- smart spaces, safe cities

Challenges

- Communication over *fading* channels
- Limited *bandwidth* and processing *power* per sensor
- Inherent limitations in sensor *dynamic range* and *resolution*
- *Latency*-critical information transfer
- *Heterogeneous* networks
- *Spatial* and *temporal variability* in sensor resources and sensor data fidelity

Minimal-Delay Encoding Communication and Fusion





Algorithms for

- signal encoding at sensors
- communication of encodings to host
- fusion of received encodings at host

Related Work

- Coding theorem for noisy sources
  [Berger 1971], [Wolf & Ziv 1970]
- Encoding/reconstruction algorithms (noisy sources)
  [Ephraim & Gray 1988]
- The CEO problem
  [Berger 1996]

Methodology

Hierarchy of algorithms that

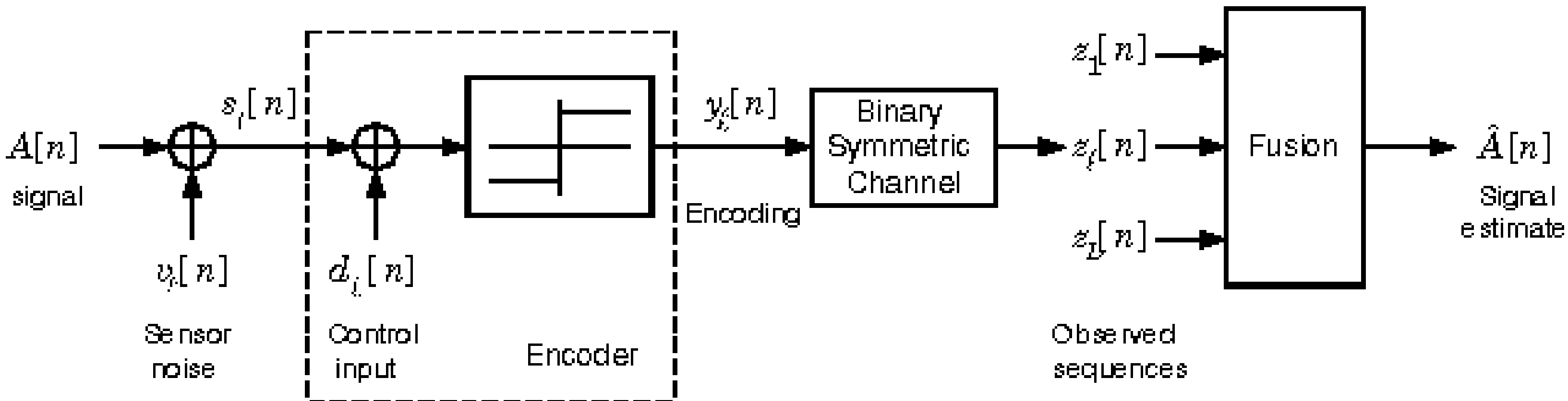
- are progressively refinable
- trade fusion performance for sensor processing complexity
- readily scale with the number of sensors and bandwidth
- accommodate large scale data fusion

Fusion over Discrete Memoryless Channels

Setting

- state-space model based signal representation
- orthogonal power-controlled multisensor communication over slowly-varying flat fading channels
- need for minimal delay in communicating measurements

Fusion over Binary Symmetric Channels

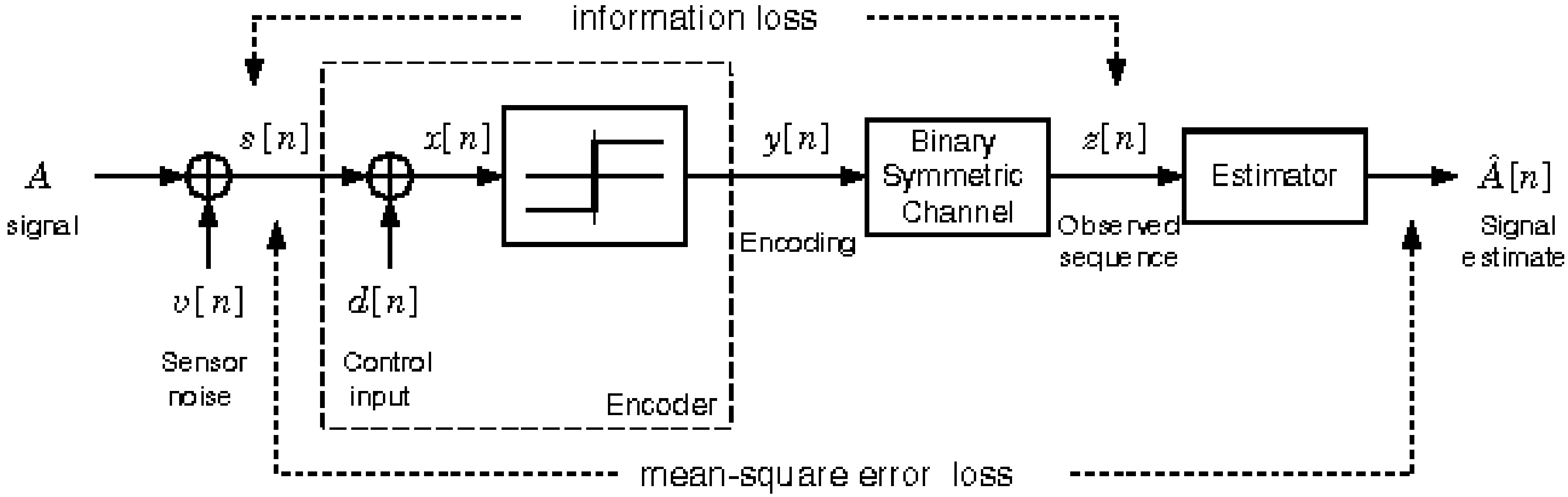


- Encoder
  - additive control input followed by scalar quantizer
- Fusion
  - host obtains signal estimate via received encodings

Estimation of AR(1) Process

- Encoder design:
  - combination of *pseudorandom* and *feedback-based* control
- Fusion method:
  - spatial fusion to produce intermediate data sequence
  - extended Kalman filter with intermediate sequence as measurements

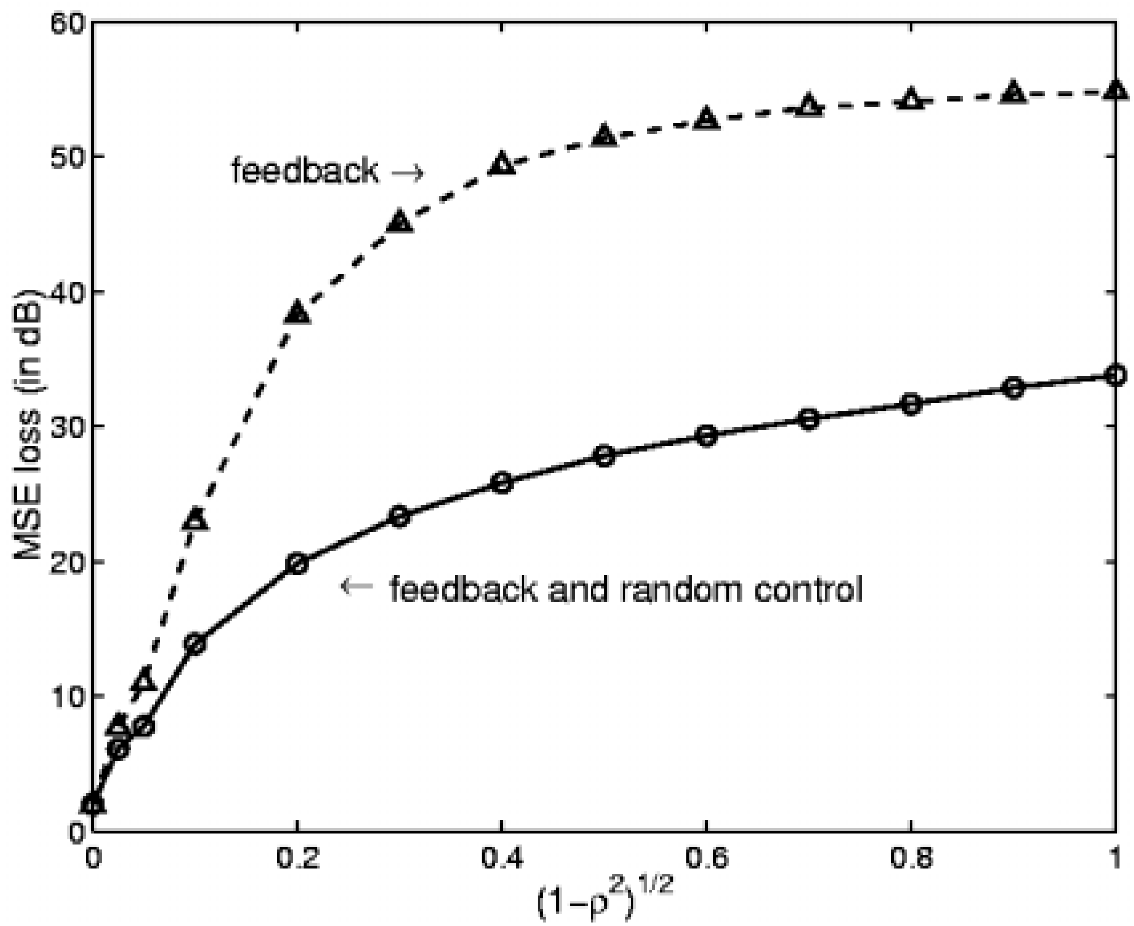
Performance Metrics



- **Information loss**: performance loss from using received encodings (instead of sensor measurements) for fusion
- **MSE loss:** fusion performance loss of overall system compared to best system operating on sensor measurements

MSE Perfomance vs. Signal Bandwidth

- Example: 100 sensors, BSC BER=0.05



Remarks

- Feedback is effective in improving over decentralized performance
- Encoding *running estimates* at each sensor
  - yields *improved fusion characteristics*
  - at expense of *higher sensor* encoder *complexity*
- Approaches have been extended over fading channels with no power control
- Hierarchy of algorithms with performance-complexity tradeoffs

Communication and Fusion over Fading Channels

- Setting
  - sensors communicate over shared bandwidth
- Cases
  - sensors may/may not have channel state information available
  - a lot vs. scarce bandwidth per sensor
  - synchronous vs. asynchronous multisensor communication
  - partial vs. no information exchange among collocated sensors

Communication and Fusion over Fading Channels

- Abundant bandwidth (≥ "1 slot/sensor meas."), orthogonal multisensor signaling
  - detection of individual sensor encodings
  - fusion of detected encodings
    - both spatial averaging and diversity benefits
- Limited bandwidth (*e.g*. "1 slot/L sensor meas."), perfect channel side info at each sensor
  - beamforming and fusion
    - both spatial averaging and diversity benefits

Methodology/Objectives

- Multiuser cooperative signaling to achieve
  - (transmit antenna) diversity benefits
  - fusion benefits

  as a function of
  - available bandwidth per sensor
  - available channel information to sensor
  - allowed processing delay
- Schemes that scale with
  - available bandwidth
  - number of sensors, and transmit/receive antennae

Wireless Relays *(cont.)*

Methodology/Objectives:

- Power-optimized relaying strategies as a function of
  - bandwidth expansion
  - available information at transmit sensors/relays
  - allowed processing delays
- Centralized vs. decentralized relaying algorithms