Real-time Systems

- Many wireless sensor network applications require real-time support
  - Surveillance and tracking
  - Border patrol
  - Fire fighting
- **Real-time systems:**
  - Hard real-time: guarantee deadlines
  - Soft real-time: improve miss ratio
  - Differentiation

Real-time Systems

- Concerned with two aspects:
  - **Control**
    - RAP
  - **Prioritization**
    - SPEED
    - CODA

Modeling the sensor networks

- A sensor:
  - Limited memory
  - Limited processing
- **Communication:**
  - Scarce bandwidth
  - Voids exist
  - Energy intensive
  - Communication generates congestion hot-spots
  - MAC layer may provide QoS
  - end-to-end communication time depends on single-hop delay and the distance it has to travel

Modeling the sensor networks

- Tight integration with the physical world
- Location aware
- Communication patterns:
  - Local coordination
    - Sensors coordinate with one another (usually by defining a group) in order to aggregate data
    - Usually involves a small number of hops
  - Sensor-base communication
    - Sends data from the local group to the base station
    - Requires multiple hops
Contributions

- A high level architecture for large wireless networks
  - Ability to define queries
  - Use event services
- Velocity Monotonic Scheduling (VMS)
  - A policy for scheduling packets in a sensor network

Design Goals

- Provide APIs for micro-sensing and control
- Maximize the number of packets meeting their E2E deadlines
- Scale well to large number of nodes and hops
- Introduce minimum communication overhead

RAP Stack

Query/Event Service API

- Query
  - attribute list
  - area
  - time constraints
  - querier location
- When an event is detected, the query is started and periodically generates result

Location-Addressed Protocol

- Connectionless transport layer
- Address is based on geographic location
- Services:
  - Unicast
    - Deliver a node closest to the destination
  - Area multicast
    - Deliver to all nodes in an area
  - Area anycast
    - Deliver to any node in the area

Geographic forwarding

- Greedy algorithm
  - Selects the node with the shortest geographic distance to the packet's destination
  - At every step the packet gets closer to the destination
- Works really good for high density network
Velocity Monotonic Scheduling

- FCFS policy is generally used in sensor networks
  - Works poorly for real-time systems
- VMS
  - It is both deadline and distance aware
  - Assigns priority based on the requested velocity
  - A higher velocity denotes higher priority

Velocity Monotonic Scheduling (2)

- Static monotonic velocity (SMV)
  \[ y = \frac{(x_i - x_j)^2 + (y_i - y_j)^2}{D} \]
- Dynamic monotonic velocity (DMV)
  \[ T_j - \frac{(x_i - x_j)^2 + (y_i - y_j)^2}{D - D_j} \]

802.11 Overview

- 802.11 has two coordination functions
  - Point Coordination Function (PCF)
  - Distributed Coordination Function (DCF)
- Two access methods
  - Basic access method
  - RTS/CTS

802.11 Basic mechanism

- A station monitors the channel
  - If the channel is free for more than DIFS the station transmits
  - Before transmitting we wait for a random delay
  - Else, the channel continues to monitor the channel until it is free for DIFS
- To avoid capture effect, the station needs to wait for a period of time before sending the next packet
- Discrete time backoff as multiple of the number of slots
  - The size of the contention window increase exponentially with the number of failed attempts to send the message
- CW min – minimum contention window
- CW max = 2mCW min – maximum contention window

802.11 Basic mechanism (2)

- Exponential backoff
  - Chosen for an uniform distribution (0, w-1), where w is the contention window
  - The size of the contention window increases exponentially with the number of failed attempts to send the message
- We retry to resent the message when the backoff counter reaches zero
  - The backoff counter is decremented only when the channel is idle
  - The counter is reset to zero in the case of a successful transmission
MAC –layer prioritization

- When communicating multiple hosts compete for the shared medium
- In 802.11b all messages have the same priority
- To enforce packet prioritization MAC protocols should provide distributed prioritization on packets from different nodes
- We can change two parameters
  - The time you can wait after idle
    - DIFS = BASE_DIFS * PRIORITY
  - Backoff increase function
    - CW = CW/2 + [(PRIORITY-1)/MAX_PRIORITY]

Experiments

- Routing protocols
  - Dynamic Source Routing (DSR)
  - GF
- Scheduling
  - FCFS
  - DS – fixed priority based on their e2e deadline
  - Velocity Scheduling
    - DVS
    - SVS

Overall Miss Ratio of GF/DSR

![Graph showing overall miss ratio of DSR and GF with deadlines (5, 10)](image)

Using VMS

![Graphs comparing miss ratios of different scheduling methods](image)

State of the art

- Only a few real-time algorithms exist for sensor networks
- Routing based on sensor’s position
  - GPSR
  - GR
  - LAR
Design Goals

- Stateless
  - Information regarding the only the immediate neighbors
- Soft Real Time
  - Provides uniform speed delivery across the network
- Minimum MAC Layer support
- Traffic load-balancing
- Localized behavior
- Void avoidance

Speed Protocol

Soft Real-time

- Where is the time constraint?
  - “SPEED aims at providing a uniform packet delivery speed across the sensor network, so that the end-to-end delay of a packet is proportional to the distance between the source and destination. With this service, real-time applications can estimate end-to-end delay before making admission decisions. Delay differentiation for different classes of packets is left as future work.”
  - Try to send the packet at Ssetpoint

Delay estimation algorithm

- Due to scarce bandwidth cannot use probe packets
- Delay is measured at the sender as the difference between when the packet was queued and its ACK and the processing time on the receiver time
- Keeps track of multiple data points to compute the current delay using (EWMA): $\text{average} = \text{average} \times \alpha + \text{delay} \times (\alpha - 1)$

Delay estimation algorithm (2)

- Delay estimation beacon is used to communicate to other neighbors the estimated delay
  - Goal: allow nodes react to changes in traffic pattern [avoid congestion]

Neighbor beacon exchange scheme

- Periodically broadcasts a beacon to neighbors to exchange location information
  - In order to reduce traffic we can piggyback the information
  - Assume all neighbors fit in the neighborhood table
- Possible enhancement:
  - Advertising state changes may reduce number of beacons
  - On-demand beacons
    - Delay estimation
    - Back pressure pressure
- Fields:
  - Neighbor ID
  - Position
  - Send To Delay
  - TTL
SNGF

- Neighbor set of node $i$
  \[ N_S = \{ a | d(i, a) < \text{samp}(0) \} \]

- Forwarding candidate set
  \[ N_F = \{ a | d(i, a) < \text{samp}(0) \} \]
  - Where
    - $L = d(i, \text{destination})$
    - $L_{\text{next}} = d(\text{next}, \text{destination})$

- Relay speed
  \[ \text{Speed}(\text{destination}) = \frac{L - L_{\text{next}}}{\text{HopDelay}} \]

SNFG(2)

If $|FS_i| > 0$

if $|Viable| > 0$

candidate = choose(Viable(FS_i))

send to candidate

else

compute relay ratio

if no nodes to support $S_{\text{setpoint}}$

drop packet if a random chosen between $(0, 1)$ is bigger than the relay ratio

} else

drop packets

send pressure beacon upstream

SNFG(3)

- Delay Bound = \( \frac{L_{\text{e2e}}}{S_{\text{setpoint}}} \)
  - Where:
    - $L_{\text{e2e}}$ is the end-to-end Euclidian distance measured
    - $S_{\text{setpoint}}$ the speed maintained across the network

- Drawbacks:
  - All messages have the same speed
  - Does not take into account the link quality [same issue as GF]
  - Better measure of congestion

Neighbor feedback loop

- Goal:
  - Maintain a single hop speed above a desired $S_{\text{setpoint}}$
  - $S_{\text{setpoint}}$ is a network wide parameter that tunes how “harsh” the real-time requirements are

Neighbor feedback loop

- Rerouting due to pressure
  - The congested area is detected and the probability of sending to that node is limited

Back pressure rerouting
Back pressure rerouting(2)

- Issue:
  - Maybe reinforcement should refer to a geographic area rather than a node!

Other ways of thinking about congestion

- Congestion detection
  - Sampling
  - Queue length
- Backpressure
- Closed-loop multi-source regulation

Overall approach: Under a threshold there is no need to check for congestion. Above it, we want to detect and control congestion.

Void avoidance

- Voids occur if the density is not high enough
- Deals with voids similarly to hotspots by applying backbone pressure
- Several packets may be dropped when trying to avoid a void

Last mile processing

- Processing close to the destination area
  - Area anycast
  - Area multicast

E2E Miss Ratio

- Ssetpoint = 1km/s
- e2e deadline = 200 ms
Critiques and Possible Improvements

- Is the delay estimation correct?!?
- Combine SPEED and RAP
- Energy conservation is only secondary concern in the paper
- All neighbors can fit in the routing table
- Needs to be manually tuned
- Multiple velocities
- Can we do better for long running flows?
- How to handle mobile users?
- Can we use power control?
Questions?