Title

Multi-hop Code Distribution for Sensor Networks

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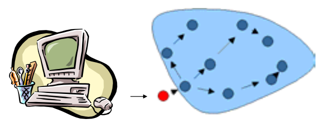
Multihop Over the Air Programming: Supporting in-situ code updates for motes

Useful for users…

Users need over-the-air code distribution to:

- **Add** new ***functionality***
- **Facilitate** ***debugging***
- **Extend** ***usefulness*** of the network
- **Program** nodes that are not ***physically reached***
- **Automate** the process to support ***large network sizes***



…and for researchers

- Special case of ***data dissemination***
  - Large ***volume*** of data
  - All nodes in the network ***must be reached***
- Strict ***reliability requirements***
  - ***Everything*** must be received
- Limited ***resources***
  - ***Low-power radios***, limited ***memory*** and ***storage***
- Helps explore sensor net design space for ***reliable communications***

Goals and Design Questions

Goals: Resource prioritization

- **Energy:** ***most important*** resource
  - Directly related to ***radio transmission*** and ***stable storage (EEPROM) access***
  - Motes must ***stay alive*** for as long as possible
- **Memory usage:** secondary importance
  - Must limit usage to ***less than 1K of RAM***, to leave enough for the ***real*** application
- **Latency**: the ***least important***.
  - Since there is ***no real-time*** requirement for this application, it can be ***traded off for energy***.

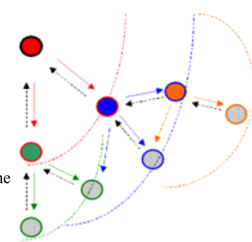
Design questions

- **Transfer protocol:** How is data propagated?
  - Stream data to all nodes at the same time (***flooding***)
  - Neighborhood-by-neighborhood dissemination (***ripple-like***)
- **Segment management on the receiver**: How to store, retrieve, keep track of segments?
  - Treat RAM + EEPROM as a ***hierarchical data structure***
  - Use a SACK-like ***sliding window***
- **Retransmission policy:** How are requests sent, how are replies generated?
  - Requests: ***Unicast*** vs ***broadcast***
  - Suppression mechanisms

Design and implementation details

Approach and analysis

- **Ripple transport protocol**: One source per neighborhood
  - Nodes ***periodically advertise*** their versions
  - Interested nodes (not already attached to a source) ***subscribe***
  - Sources without subscribers are ***silent***
  - ***Single-hop propagation*** from the source to all receivers.
  - ***Local*** repairs
  - Once a node has the ***complete image*** it sends ***publish*** messages and the process repeats itself
  - Significant expected ***traffic reduction*** compared to flooding at the expense of ***latency***



Design Alternatives

- **Segment mapping:** SACK-like sliding window
  - Problem: how does the node find ***which segments are missing***?

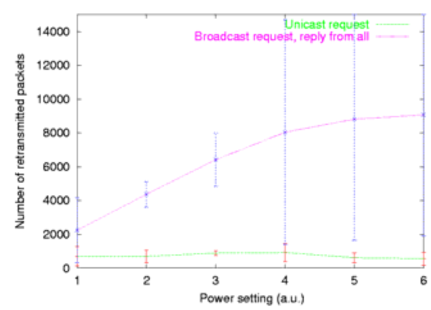
Segment mapping	RAM (bytes)	TX Cost	RX Cost	Gap detection Cost	Out-of-order tolerance
None	0	R	W always	(# of segments)*R	Complete
Full (RAM map)	512	R	W when segment missing, else 0	0	Complete
Partial (k packets per map bit)	512/k	R	KR+W when segment missing, else 0	Up to kR. Minimum R	Complete
Hierarchical full (RAM + EEPROM)	4	R	R+2W when segment missing, else R	R	Complete
Sliding window	M (usually 2-4 bytes)	R	W always	0	Up to map size

- **Retransmission policy**: Energy-latency-complexity tradeoffs

Policy	Expected number of replies	Latency	Complexity
Broadcast request, all nodes reply	$(1-p)^2(k+m)$	0	O(1)
Broadcast request, suppressible replies	$(1-p)^2\left\{1+\frac{(k+m-2)}{C}\right\}$	Up to C	O(neighborhood size) for a good estimation of C. Several timers
Broadcast request, all nodes reply with a static probability	$(1-p)^2(a_1k+a_2m)$	Depends on selection of a_1, a_2	O(1)
Broadcast request, all nodes reply with a dynamic probability	$(1-p)^2(a_1k+a_2m)$	Depends on selection of a_1, a_2	O(neighborhood size) for a good estimation of a_1, a_2
Unicast request, only publisher replies	$(1-p)^2$	Considerable if link to publisher fails, else 0	O(1). 2 extra bytes required on request packet

Preliminary results

- Comparison between two different retransmission polices



Conclusions and future work

- Design choices for the current implementation
  - ***Ripple data transfer***, with a ***publish-subscribe*** interface and late-joiner support via periodic advertisement
  - ***SACK-like sliding window*** for energy-efficient segment management and gap (loss) detection.
  - ***Unicast*** repair requests and replies from the ***original source only*** provide a large (up to 20x) reduction in the number of duplicate replies at a very low complexity cost
  - 950 Bytes RAM ***footprint***
  - The most reasonable selection for a ***low-complexity***, ***energy efficient*** mechanism, when ***loss probability is low***
  - Experimental results ***needed*** for qualitative comparisons: Ripple vs Flooding, Hierarchical segment mapping vs Sliding Window
- Several more to choose from!
  - Choosing the right segment management scheme or retransmission policy depends on the ***resource prioritization*** and the expected loss rate
  - As in many systems, there is no 'one size fits all'
- Next step: ***Deployment at James Reserve***, as part of ESS