Pub/Sub in the Air: A Novel Data-centric Radio Supporting Robust Multicast in Edge Environments

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Motivation

- Edge devices equipped with diverse sensors become pervasive
  - Vehicles/drones: cameras, LIDARs, IMUs, radars, sonars
  - Internet-of-Things: heterogeneous sensors

- Sharing data among devices enable novel futuristic applications
  - Vehicular 360° penetrating view
  - Smart environments: augmented reality + IoT controlled via in-air hand gestures

Current Wireless Stack Falls Short

- Destination/Network must be determined before transmission
  - Latencies in discovering neighbors (i.e. station and beacon)
  - Each frame carries a destination node (MAC) address

- Multicast support is largely non-existent
  - Just broadcast, lowest base rate (1 or 6Mbps)

Challenges

- Wireless medium and environment
  - Varying reception qualities at different neighboring receivers
  - Short contact durations
- Data names may have large lengths and quantities
  - MAC header needs to be of small size.
- Data sharing is mostly one-to-many
    - Multicast without prior coordination and network formation is necessary

Data-Centric Wireless Medium Access Control

- Beaconless design
  - Eliminate latency overhead
    - highly mobile environments and dense environments
- Name-based filtering
  - Wireless frames carry data attributes (e.g., names)
- Robust multicast
  - A representative receiver requests missed frames on behalf of all consumers in aggregate form
  - Sender retransmit missing frames (retransmission decisions made in MAC for low latency)

Beaconless Design

- Why no beacon?
  - Beacons are fundamentally designed for nodes to announce their mac address for address-based communication and associate.
- How do nodes join/leave network?
  - There is no more network formation, data-centric communication benefit
- What about discovering data?
  - Discovering data is network's layer job, not MAC's.

Name-based filtering

- Hash data names into an encoding (e.g., 16 bits)
  - A thin layer between network and MAC breaks and reassembles packets

- The MAC maintains a table of desired data name encodings
    - Interests from local network layer creates entries in a pending encoding table (PET) in MAC.
    - Each incoming data frame is compared against the table for matching and passed up only if a matching exists.

Robust Multicast by Data-centric ACK (DACK)

- Frame Burst: back to back transmission of data frames of the same packet
- Aggregate feedback to notify sender of missing frames after each burst
  - Spatial and Temporal: one representative feedback frame per burst
- Notify sender of missing frames after each burst
  - Sender retransmits missed frames reported

DACK Frame and Transmission

- Each receiver prepares a DACK frame reporting sequence numbers of missing frames in a sliding window of recent *k* bursts
  - Start/end sequence numbers if multiple consecutive missing frames (“holes”)
- Each receiver starts a timer, expiring after a time computed by an equation

$$T = \alpha\tau$$

  - τ: #frames received (less missing, later expiration)
  - α : backoff slot size measured from previous burst
  - Upon timer expiration, a receiver transmits the DACK
  - Upon hearing two DACKs of the current round, receiver cancels their DACK
  - The sender retransmits frames requested in that DACK

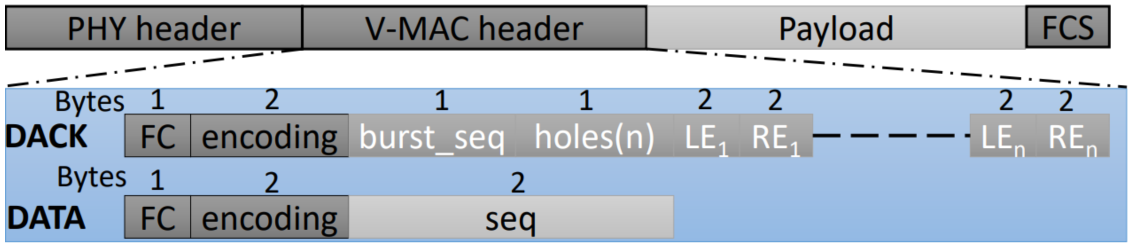
Retransmission of Missing Frames

- Retransmission buffer
  - The sender has a buffer to store recently transmitted frames in a sliding window
- Retransmission Pacing
  - A missing frame might be requested in multiple DACKs
    - 2 DACKs allowed
    - >2 may occur if not overheard by all receivers
  - Simple rule: a missing frame will be retransmitted at most once in each round
    - **result**: 0 redundant transmissions

V-MAC Frame Format

- Three kinds of V-MAC frames
  - DACK, DATA, Interest (FC, encoding, payload, FCS)
- Interoperation issues with regular 802.11
  - When encoding field matches BSSID, sequence number will be interpreted as new source MAC address
  - “stations” created until running out of memory (good DoS tool!)
- Solution: add an 802.11 header
  - V-MAC to WiFi
    - Set BSSID to that of the receiver WiFi node; Destination to broadcast
    - Regular WiFi will receive them as broadcast in that group
  - WiFi to V-MAC
    - V-MAC passes regular WiFi broadcast to upper layer
  - Bi-directional communication achieved

V-MAC frame format



V-MAC frame format with WiFi interoperability

Testbed Experiment Setup

- Raspberry Pi + USB Wifi dongle
- v3: kernel module from scratch
- 10 trials for each experiment
  - Each trial has 1 Interest sent, then 500 data frames each with 1024 bytes payload back
  - Alternate between WiFi ad hoc and V-MAC for every trial
  - 54 Mbps
- Scenarios:
  - Stationary
  - Mobility (low, medium, and high)

Stationary testbed

Real Vehicles

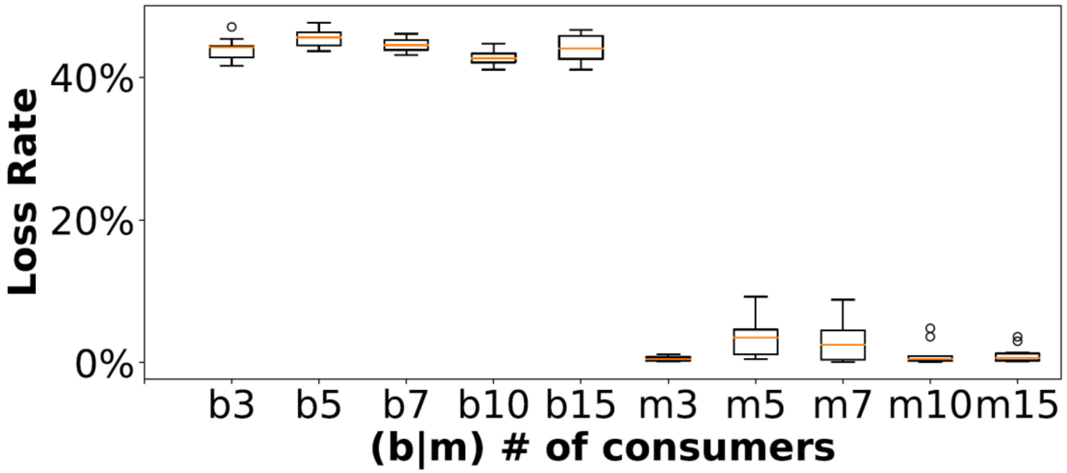
RC-Cars

System Benchmarks

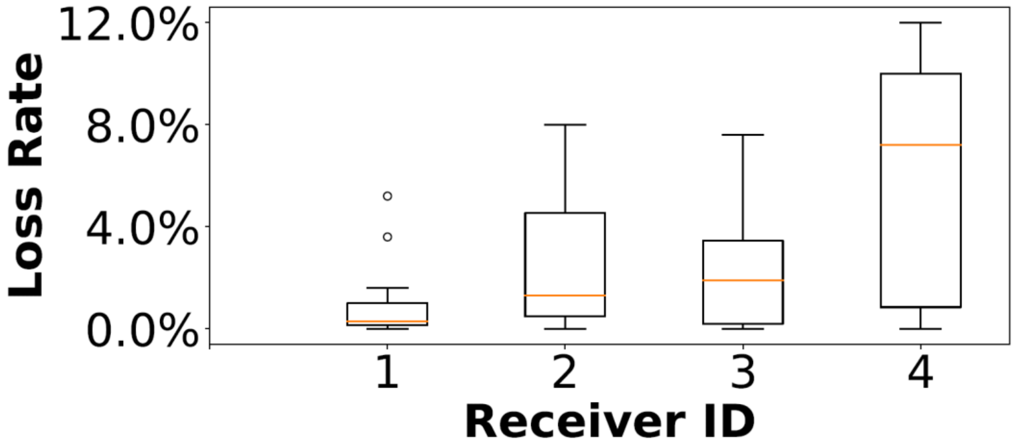
- Improved cross stack latency than standard stack
  - Tx path delay 73 microseconds (128x faster)
  - Rx path delay 70 microseconds (>40x faster)
- Attribute based filtering tested up to 2M concurrent entries
  - With 0.5X filtering latency compared to 802.11 MAC address
- System stability validated
  - System kept running for over 7 days transmitting 1000 frame every 3 minutes to 3 consumers.

Stationary and Mobile Evaluation

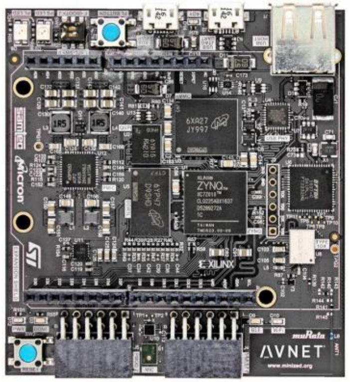
Stationary Scalability Test



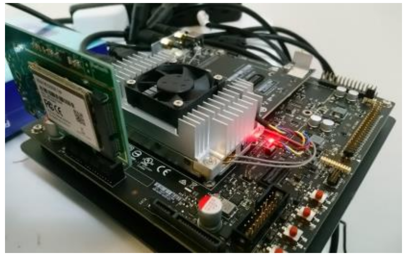
Real Vehicles Loss Rates (platoon scenario)



Conclusion



- Efficiency by data-based filtering
  - Eliminate discovery, group formation latencies and overhead
  - Retain any useful overheard content
- Multicast robustness by aggregate feedback and retransmission
  - Scalable and consistent low frame losses across receivers of varying reception qualities
  - Decisions made at MAC for fast actions
- Robust, efficient and fast prototypes ready for applications
  - Pi + WiFi dongles, FPGA, Rock64, Jetson, …
  - Available at 6 different kernel versions (3.x, 4.4, 4.8, 5.0, …)



Questions?

Joint work with Fan Ye, Peter Milder, Yuanyuan Yang

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