A Decentralized Medium Access Protocol for Real-Time Wireless Ad Hoc Networks With Unreliable Transmissions

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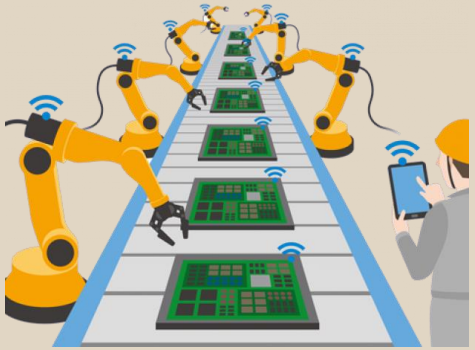
Joint work with Ping-Chun Hsieh

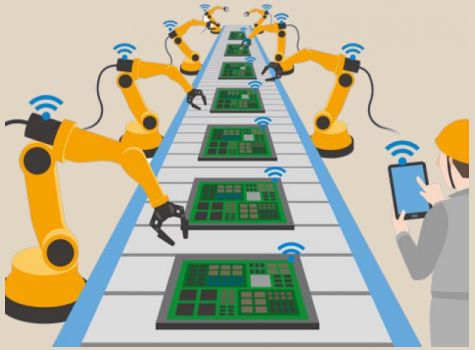
Background: Factory IoT

- Factory IoT: Connect sensors and actuators through wireless



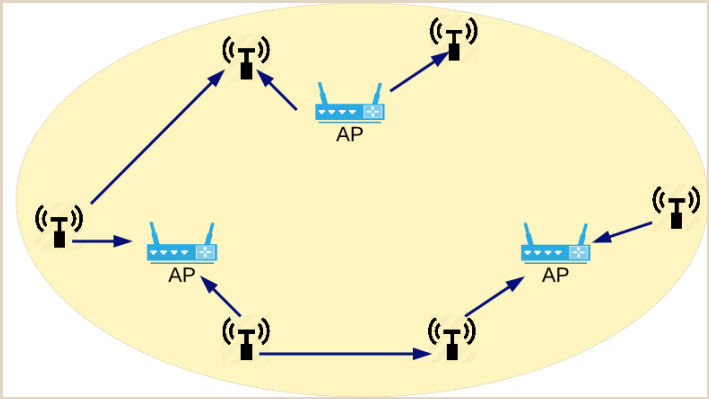
Background: Factory IoT

- Factory IoT: Connect sensors and actuators through wireless
- Sensors: Generate packets from sensed data
  - Unpredictable traffic patterns
- Actuators: Make decisions based on received packets
  - Safety relies on strict delay/reliability guarantees
- Wireless:
  - Transmissions are unreliable
  - Wireless links interfere with each other

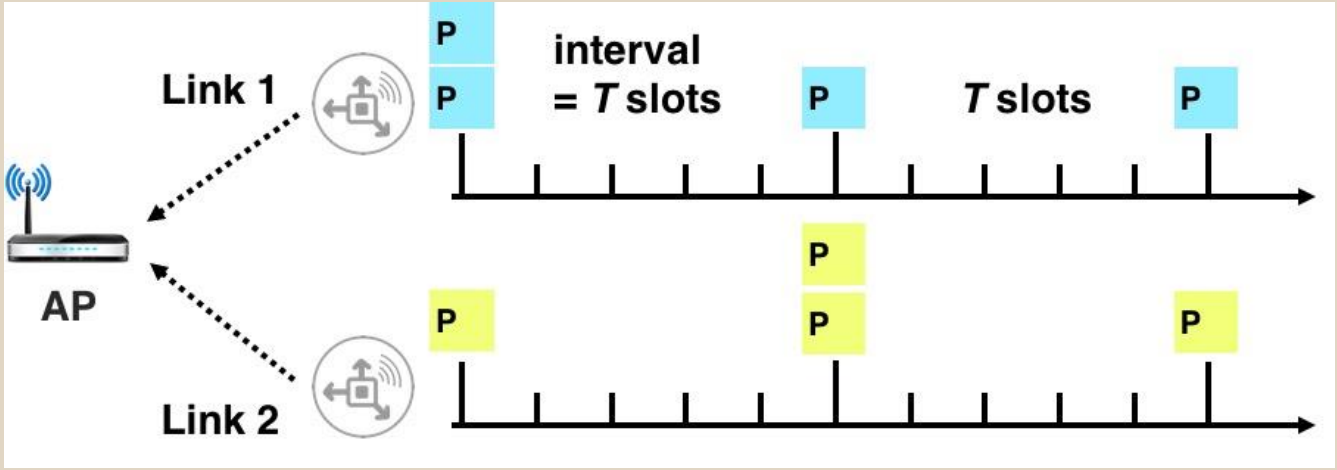


Network Topology

- A system with many sensors and APs
- A total of N links (uplink/downlink/M2M)
- All links interfere with each other, but nodes cannot overhear others' transmissions
  - Interference range > transmission range
- Nodes have perfect carrier sensing capabilities
  - Avoiding hidden terminal by setting a low CS threshold
- Each link carries a real-time flow with hard delay/reliability requirements

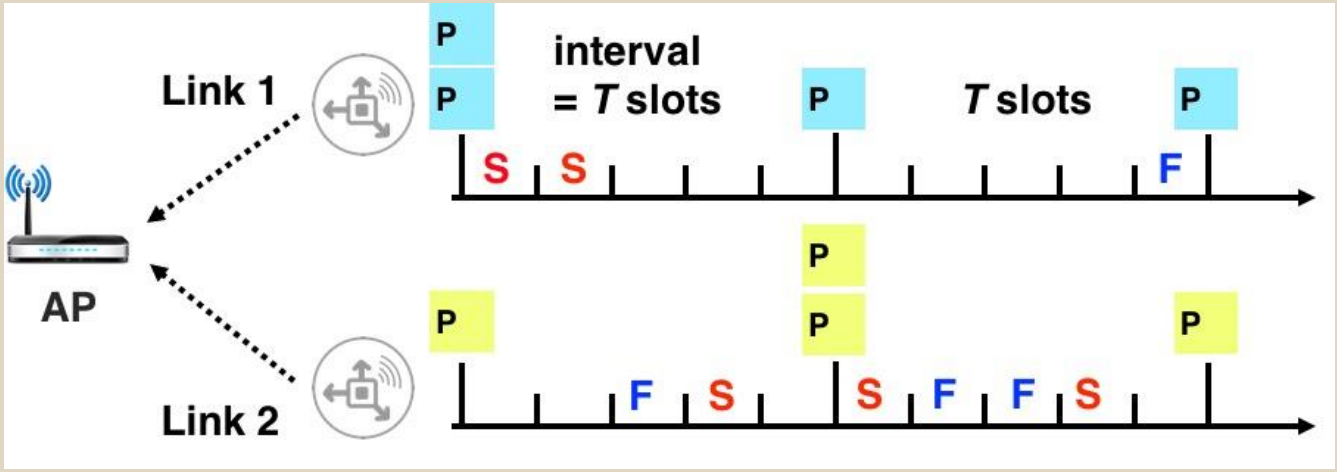


Packet Arrivals and Departures



- Time is divided into intervals. One interval = T transmissions
- At the beginning of each interval, each link generates a random number of packets
- At the end of each interval, all undelivered packets are dropped
  - Delay of each delivered packets $\leq T$

Wireless Transmissions and Service Requirements



- Only one link can transmit at any time
  - Multiple simultaneous transmissions lead to collision
- Each transmission of link n is successful with probability p_n
  - Transmissions can fail due to channel fading
- Each link n requires that its timely-throughput is at least q_n packets/interval

Goal of This Work

- Design a decentralized protocol that delivers q_n timely-throughput for each link n, whenever it is theoretically feasible to do so

- Such a protocol is called feasibility-optimal

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- Packets arrive randomly, and links have no knowledge about others' packet arrivals
- Transmissions are unreliable, and links cannot overhear others' transmissions

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- Packets arrive randomly, and links have no knowledge about others' packet arrivals
- Transmissions are unreliable, and links cannot overhear others' transmissions
- → A link cannot know the performance of other links
- → It cannot even know whether a transmission is successful

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- Propose a protocol that maintains an ordering among links to avoid transmission collisions
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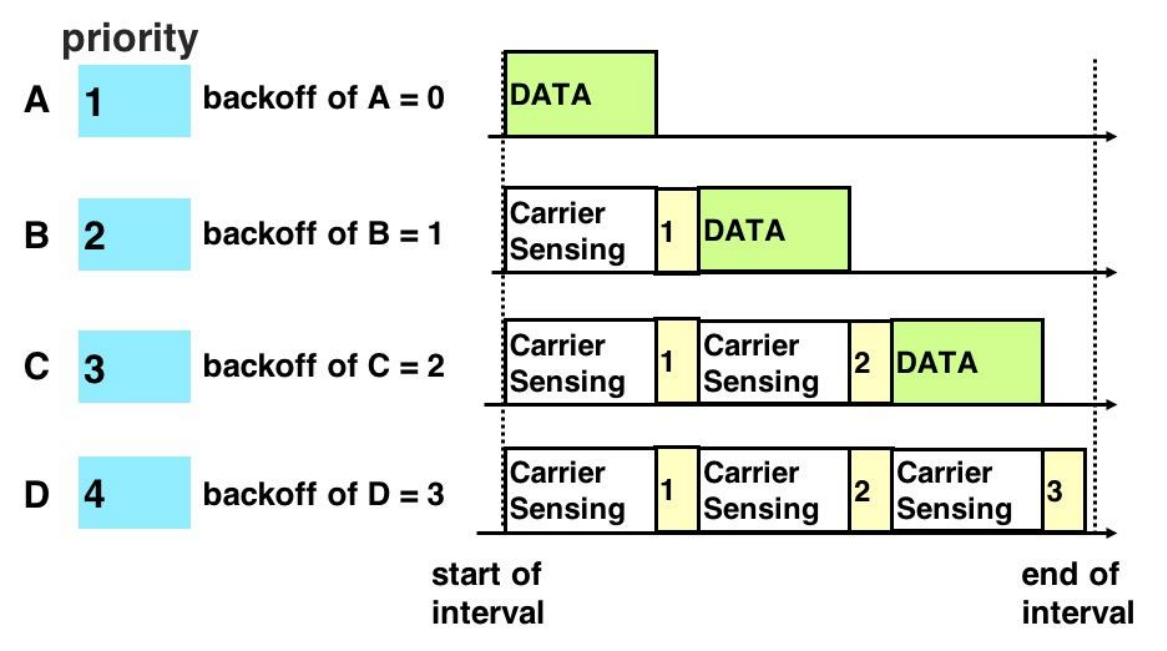
  - Small and bounded overhead
- Propose an algorithm that is feasibility-optimal

Protocol Overview: System Startup

- At startup, a centralized controller determines a priority ordering among links randomly
- The controller informs each link of its position
  - No two links have the same position
- The controller also notifies all links of a common random seed
  - All links can generate a common sequence of psuedo-random numbers in the range $[0, N-1]$

Protocol Overview: Collision-Free Transmission

- The link of priority n only begins to transmit after it senses $(n-1)$ units of channel idle time



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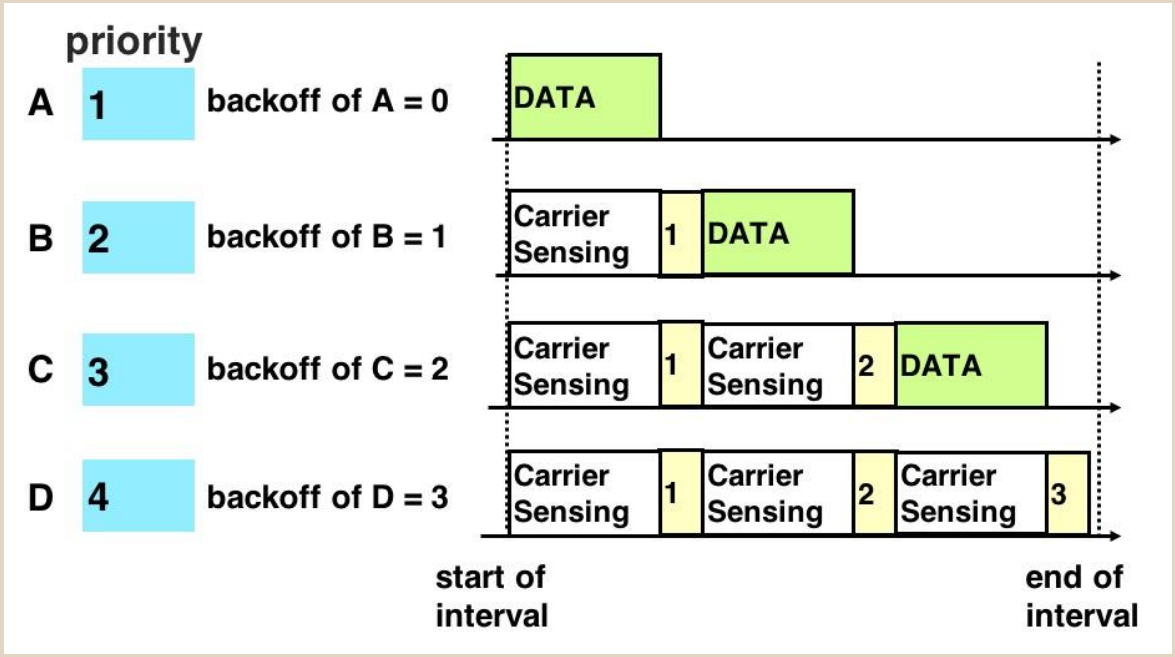
- Similar to the backoff policy in WiFi
- Total idle time $\leq (N-1)$ units
- WiFi: tx time ~ 100 time units



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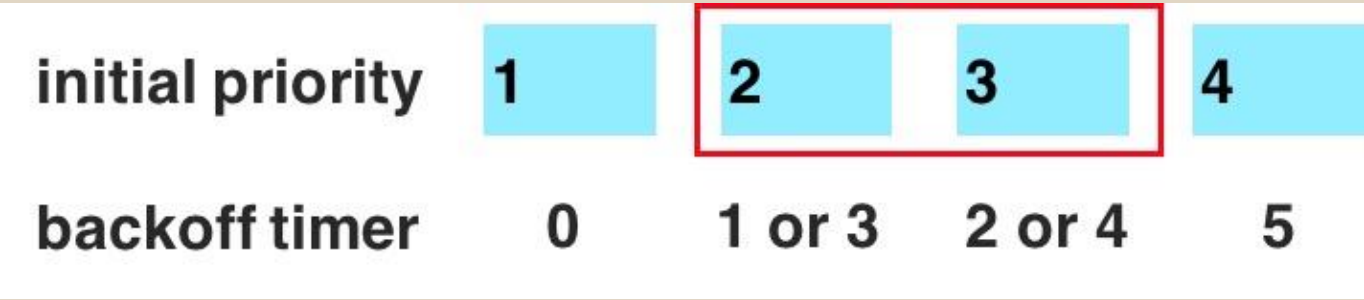
- Position R_k: Choose backoff from $\{R_k - 1, R_k + 1\}$
- Position $R_k + 1$: Choose backoff from $\{R_k, R_k + 2\}$
- Position $m, \mathrm{m} > R_k$: Backoff = $m + 1$



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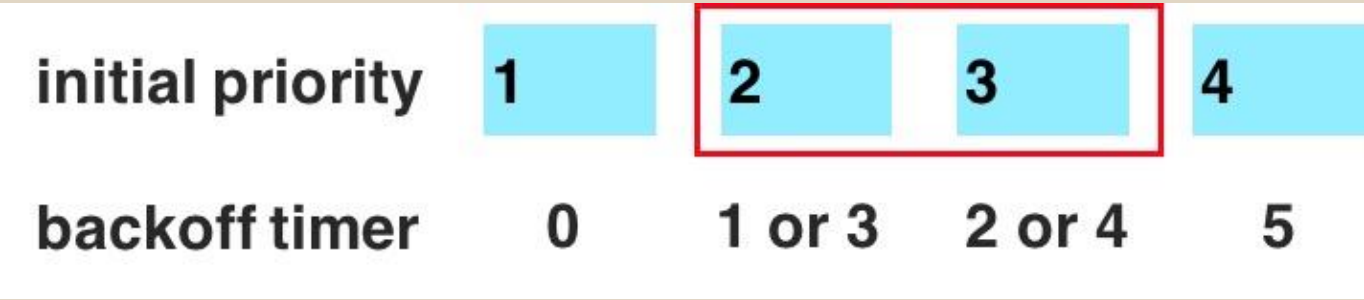
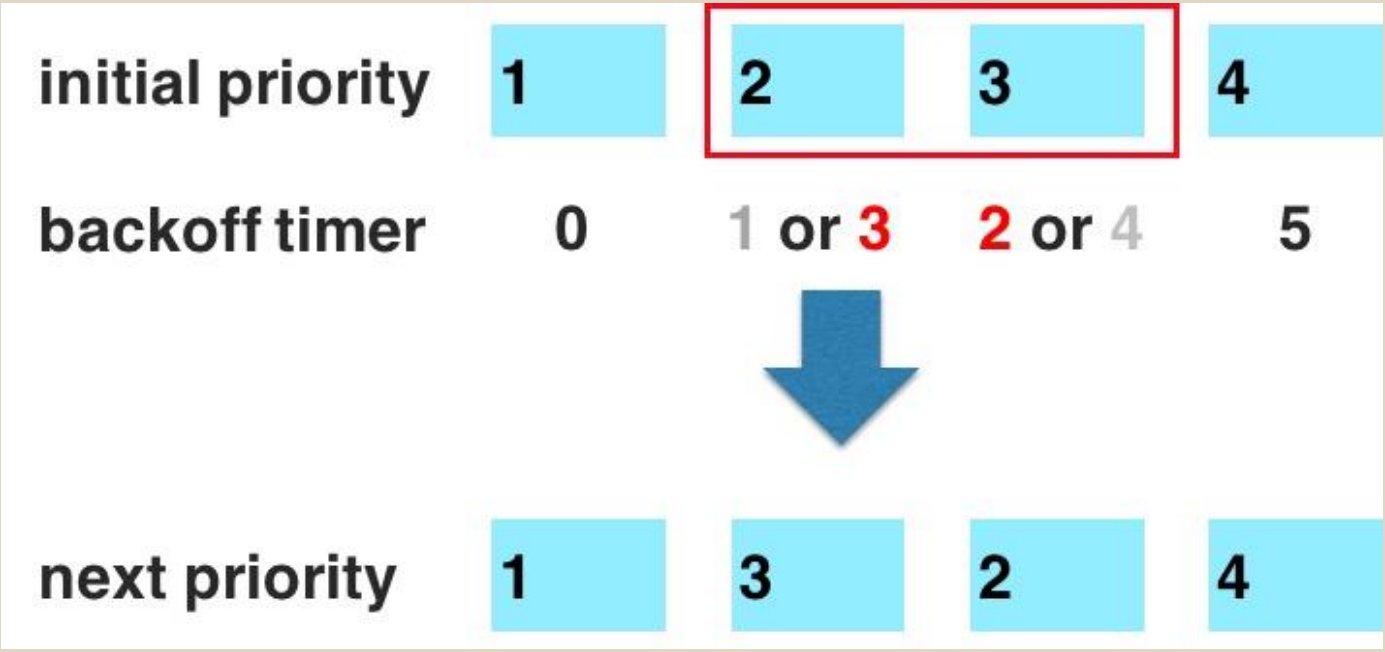
- All backoff timers are different →No collision!



Protocol Overview: Exchanging Priority Positions (II)

- Positions R_k and $R_k + 1$ change positions only when position R_k chooses backoff $= R_k + 1$, and position $R_k + 1$ chooses backoff $= R_k$
- This event can be detected by carrier-sensing



Protocol Summary

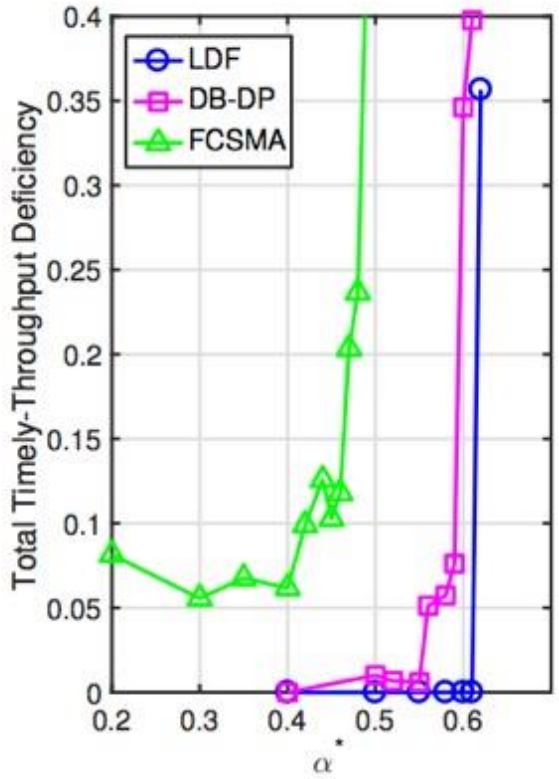
- The centralized controller is only involved in determining initial priority ordering and common random seed at startup
- Collision-free transmissions are achieved through carrier sensing and backoff timer
- The change of priority ordering is also done through carrier sensing and backoff timer

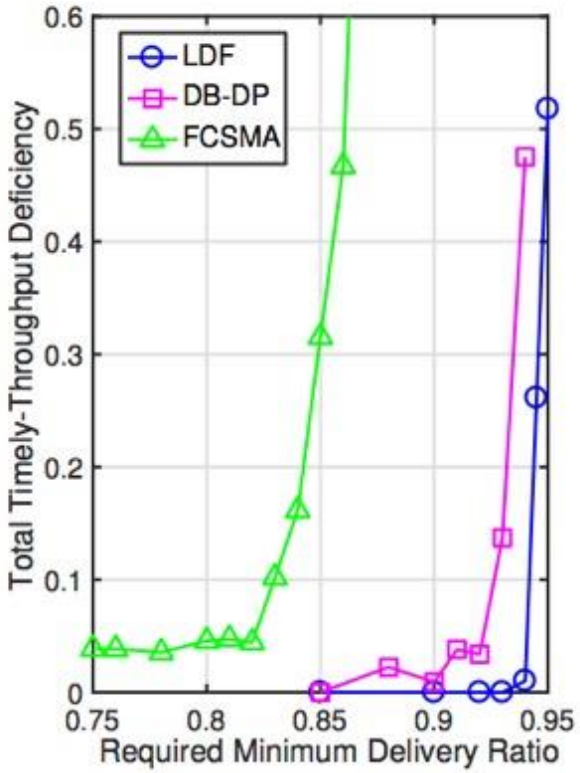
NS3 Simulation Settings

- Simulations under 802.11a standard
  - Data rate = 54 Mb/s; Unit time for backoff = 9 us
- Policies:
  - Our proposed protocol (DB-DP)
  - LDF: Centralized policy. No overhead at all
  - FCSMA (by Li and Eryilmaz): Provably optimal without guarantees on overhead
- Metric: total timely-throughput deficit

  $\sum(q_n$ −Actual timely-throughput of $n)^+$

Simulation Results





DB-DP achieves almost the same throughput as LDF

Conclusions

- Consider the problem of scheduling wireless transmissions for real-time traffic

- Propose a decentralized protocol
- All coordination is carried out through carrier sensing and backoff timer

- Propose a policy for choosing backoff timer
- The policy is provably optimal with bounded overhead