LiSCAN: Visible Light Uni-Directional Control Channel for Uplink Radio Access

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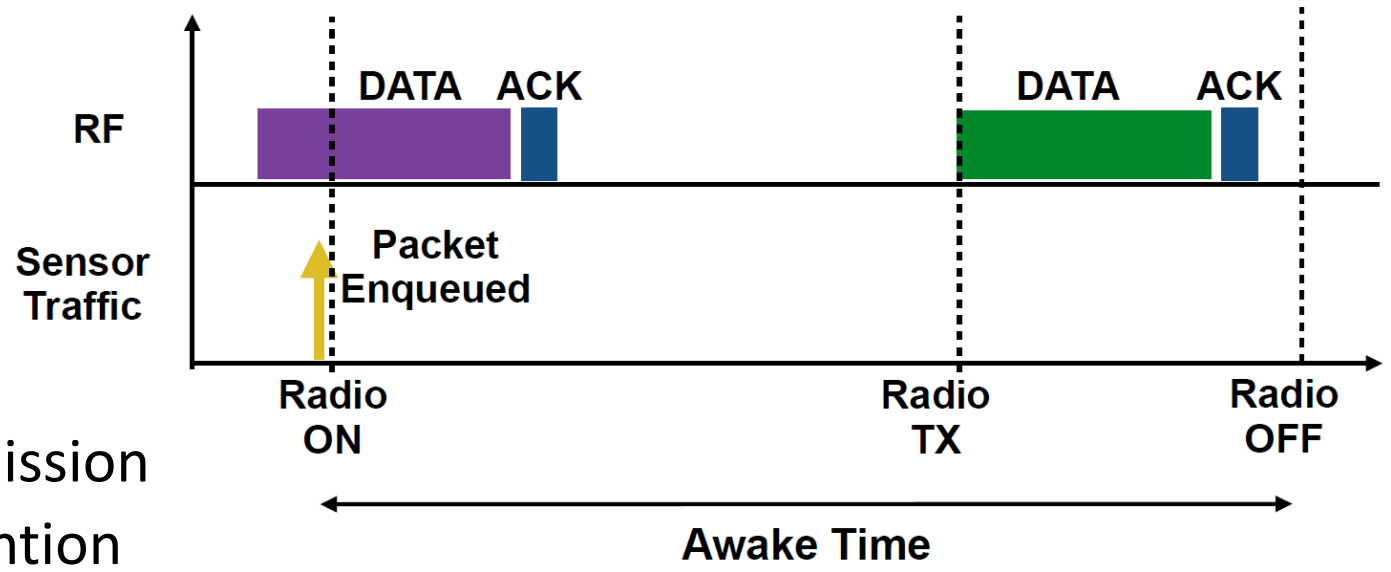
Dense Wireless Sensor Networks

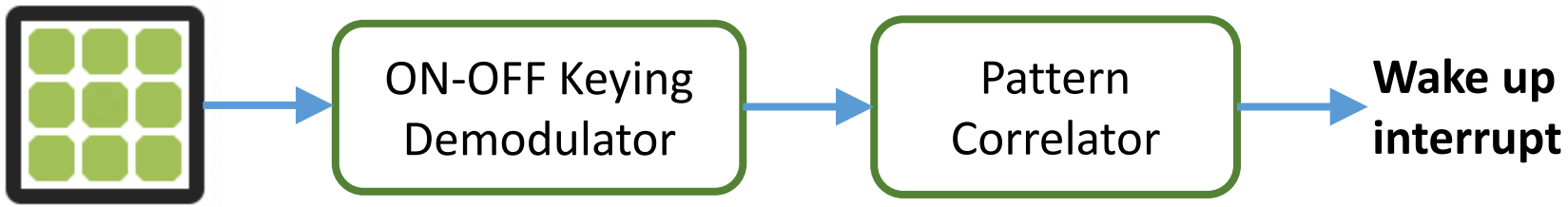
- Network Model
  - Hundreds of sensors
  - Data flow mainly in the uplink
- Sensors
  - Low-cost, power-limited
  - Ideally, only awake for data transmission
  - Access delay increases with contention
- Traffic Model
  - Asynchronous traffic patterns
  - AP lacks perfect knowledge of when a sensor generates new data

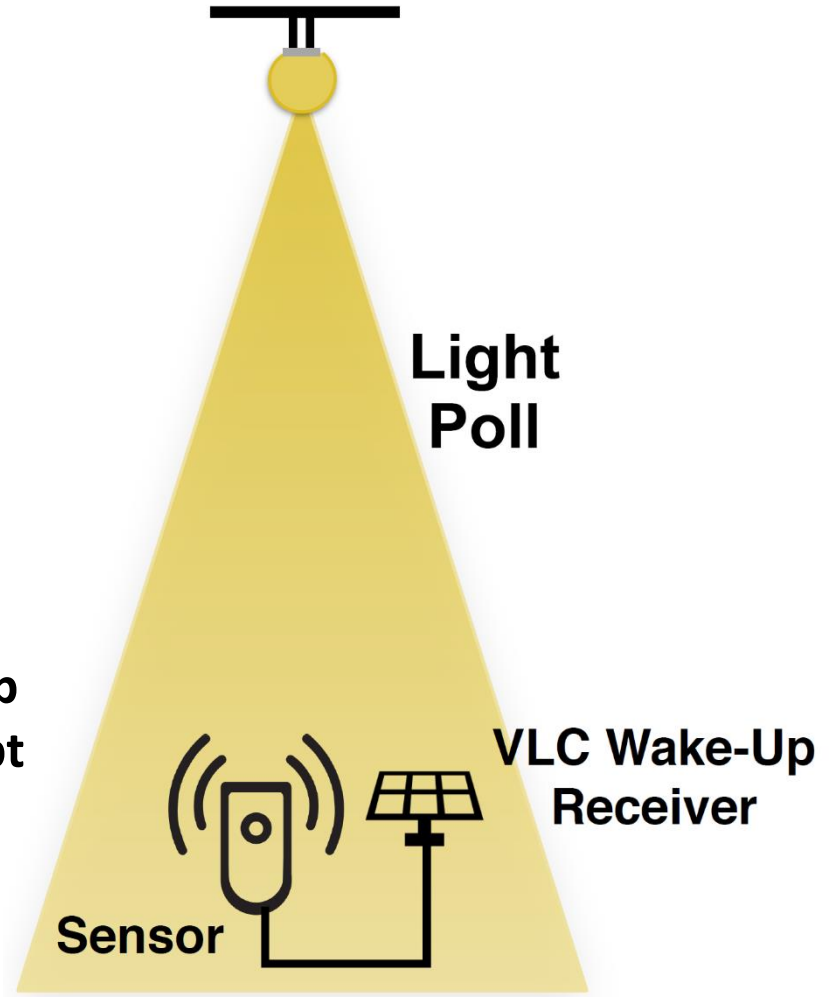


Access delay and energy consumption can be significant with radio-only protocols in dense networks

VLC Contention Free Access

- Inherent broadcast
  - Distributed LED bulb luminaries for coverage
- Energy-autonomous Wake-up VLC receiver [1,2]
  - Tens of microwatt
  - Solar panel-based energy harvesting

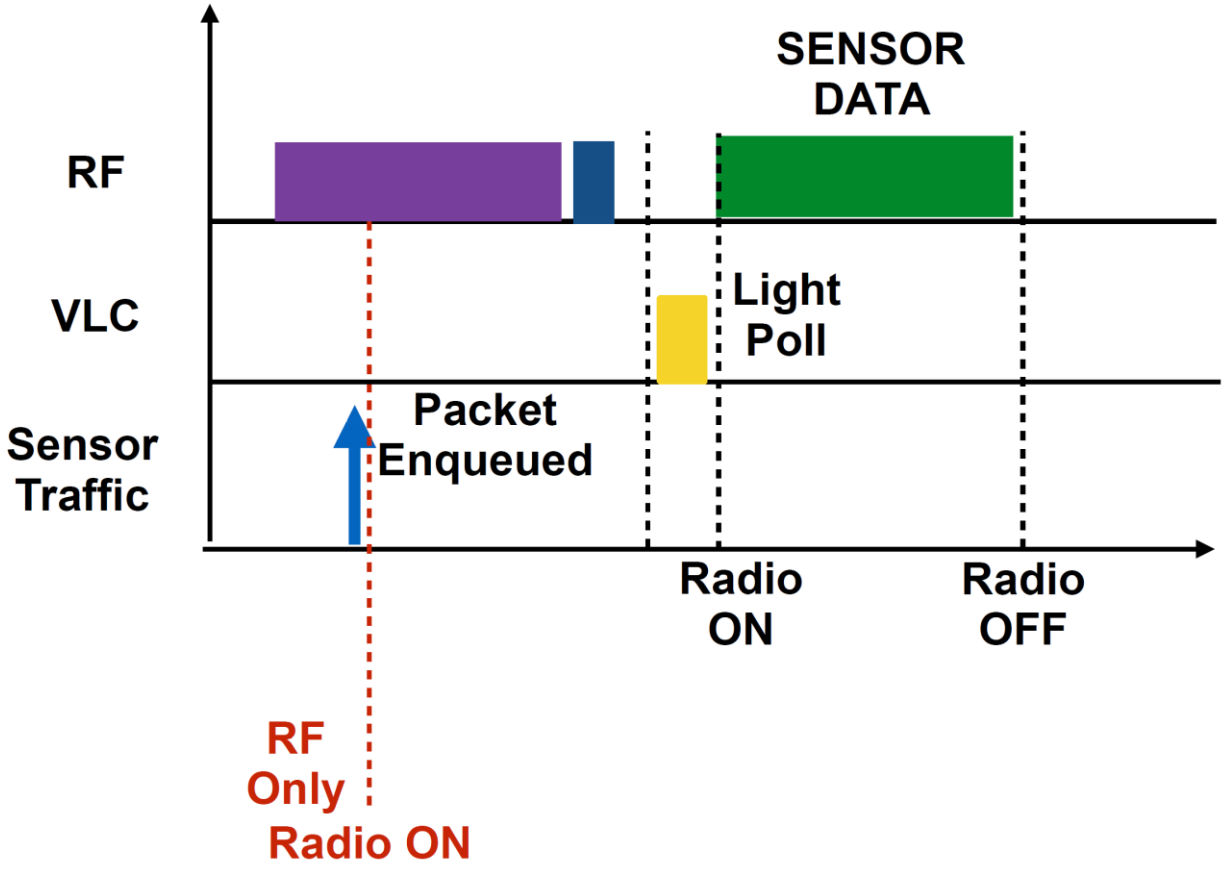




[1] J. S. Ramos et al., “Towards energy-autonomous wake-up receiver using Visible Light Communication,” in *Proc. of IEEE CCNC*, 2016.
[2] C. Carrascal et al., “A novel wake-up communication system using solar panel and Visible Light Communication,” in *Proc. of IEEE GLOBECOM*, 2014.

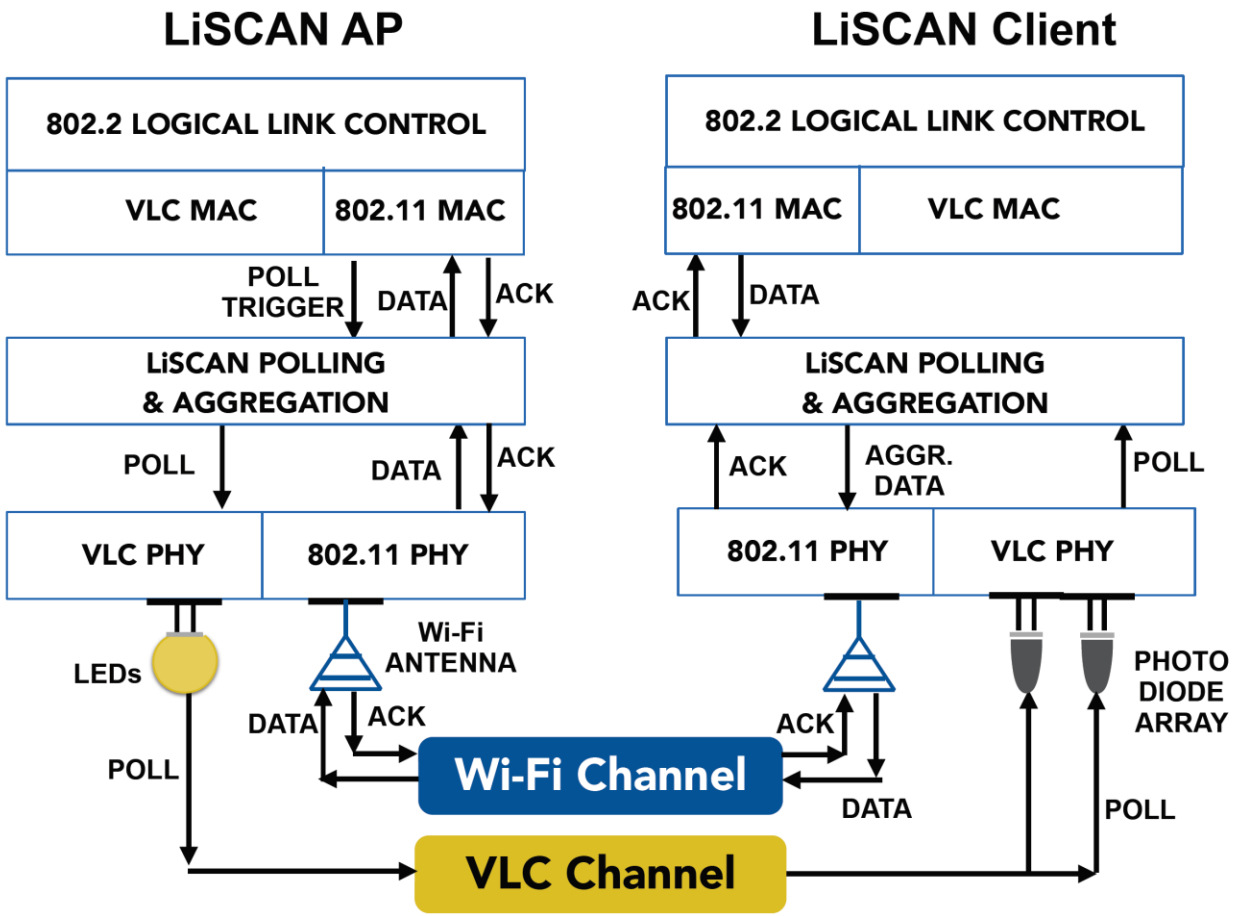
VLC Contention-Free Access

- Minimize energy consumption
  - VLC wake-up receiver turns on radio (RF) module only for data transmission



LiSCAN

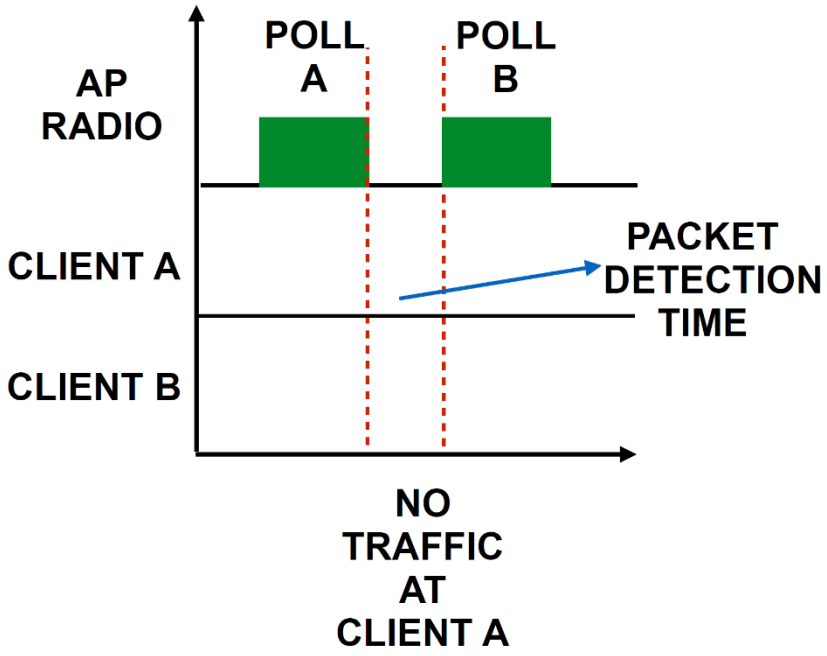
- **Architecture**
  - VLC and Wi-Fi integrated at MAC layer
  - Single layer-2 interface
- **Protocol**
  - Pre-emptive interference avoidance
  - Pipelined polling with ACK over VLC



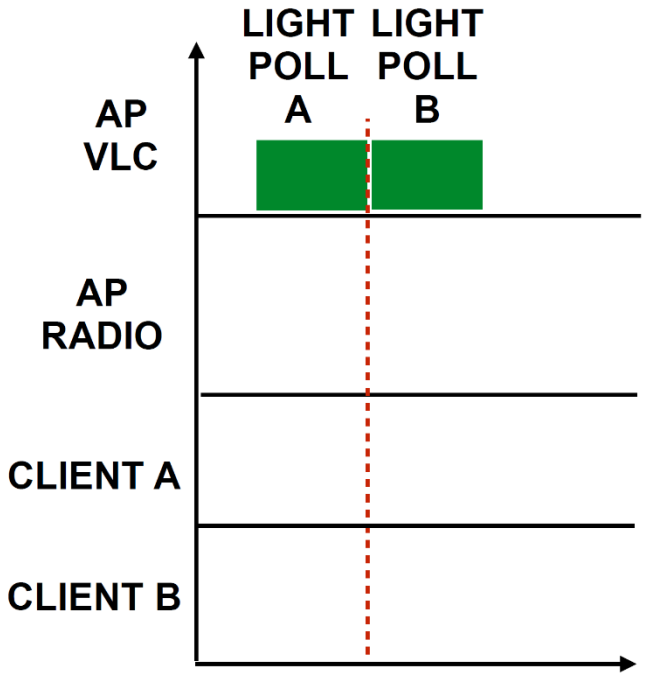
Contention-Free Access (1/2)

Sensor traffic generation unknown to AP

- RF Only

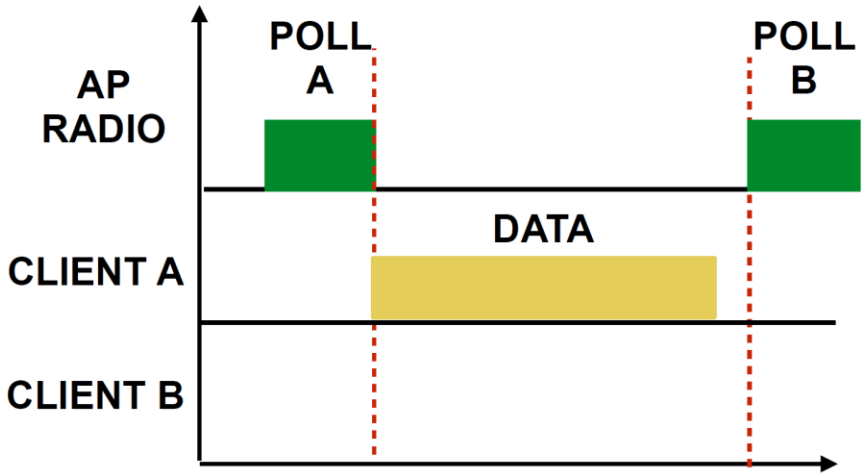


- VLC Control

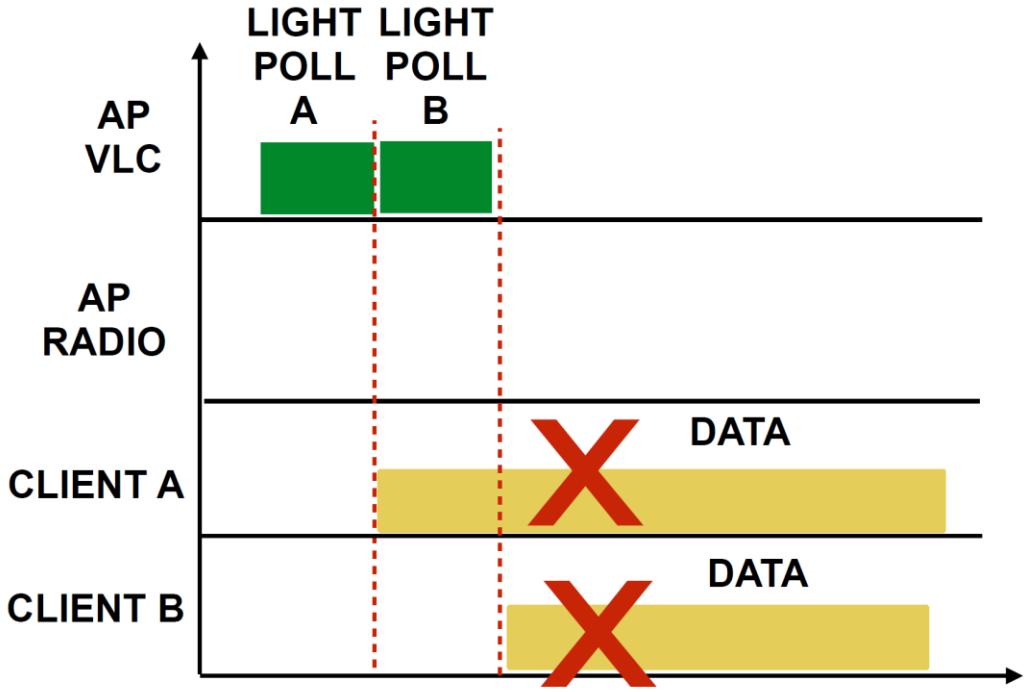


Contention-Free Access (2/2)

- RF Only

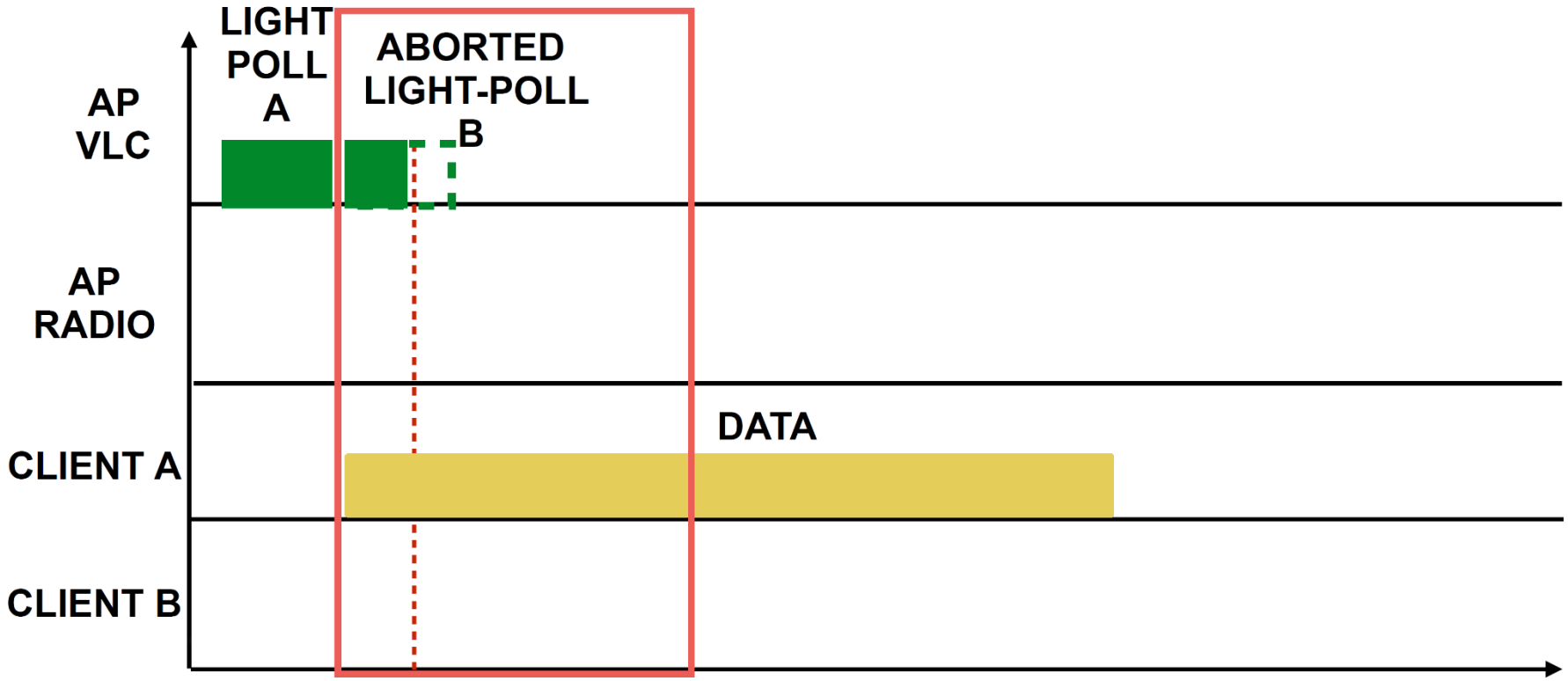


- VLC Control



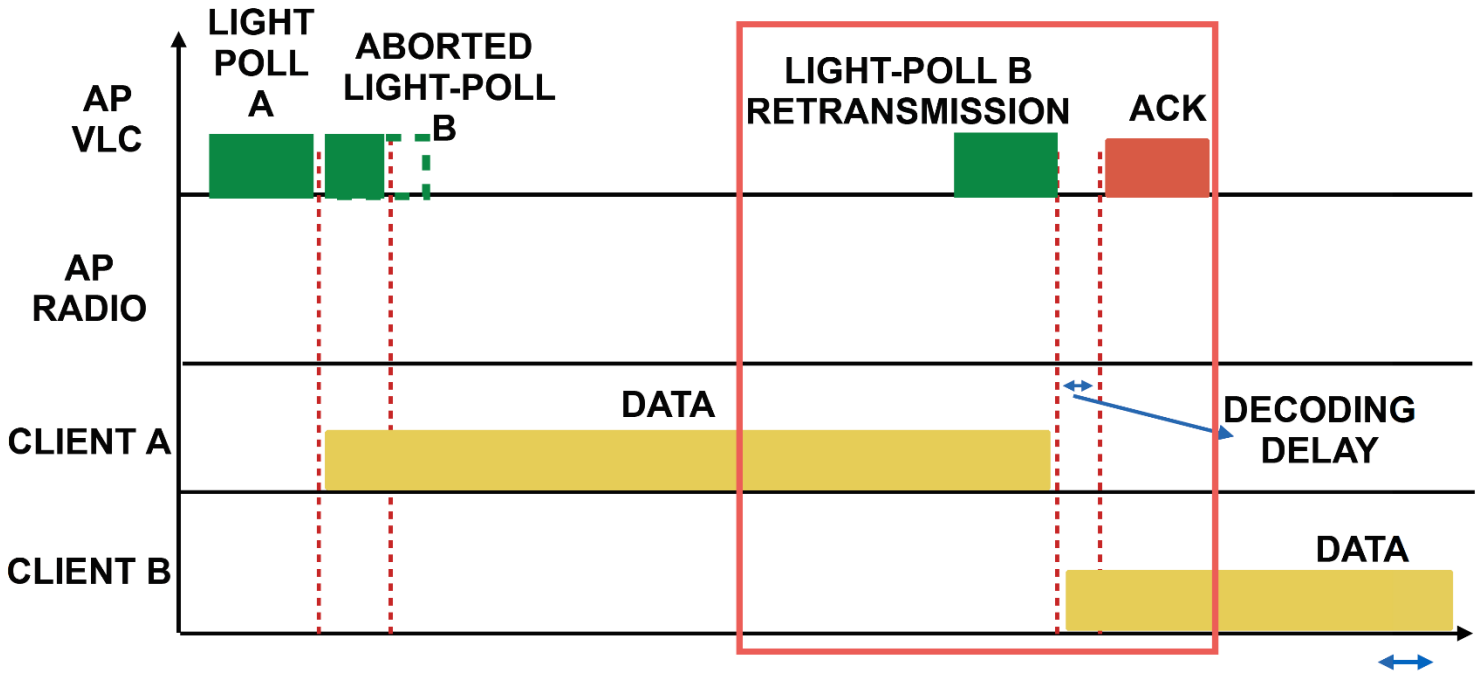
Can we perform pipelined polling and still avoid collisions?

LiSCAN Pre-emptive Collision Avoidance



- Light Poll aborted by AP upon detecting PHY preamble on RF channel
  - Client A's transmission in above example

LiSCAN ACK over VLC

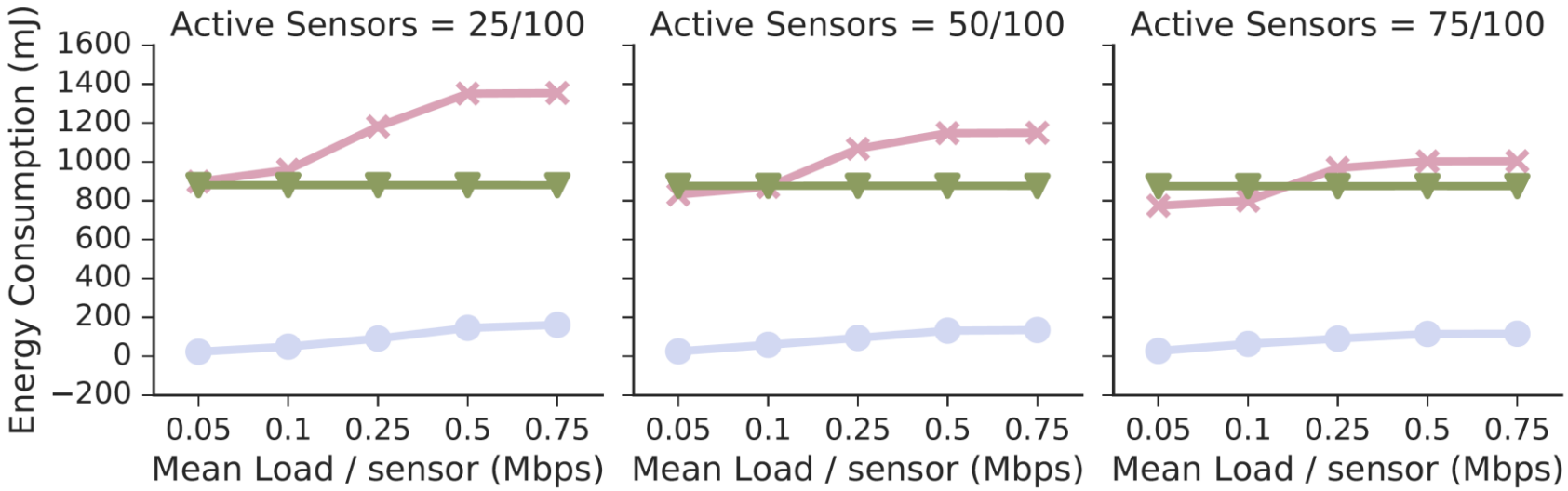


- Light Poll Retransmission Alignment
  - Enables pipelined uplink transmission increasing RF channel utilization
- ACK over VLC
  - Minimizes the energy consumption at sensor

LiSCAN Evaluation

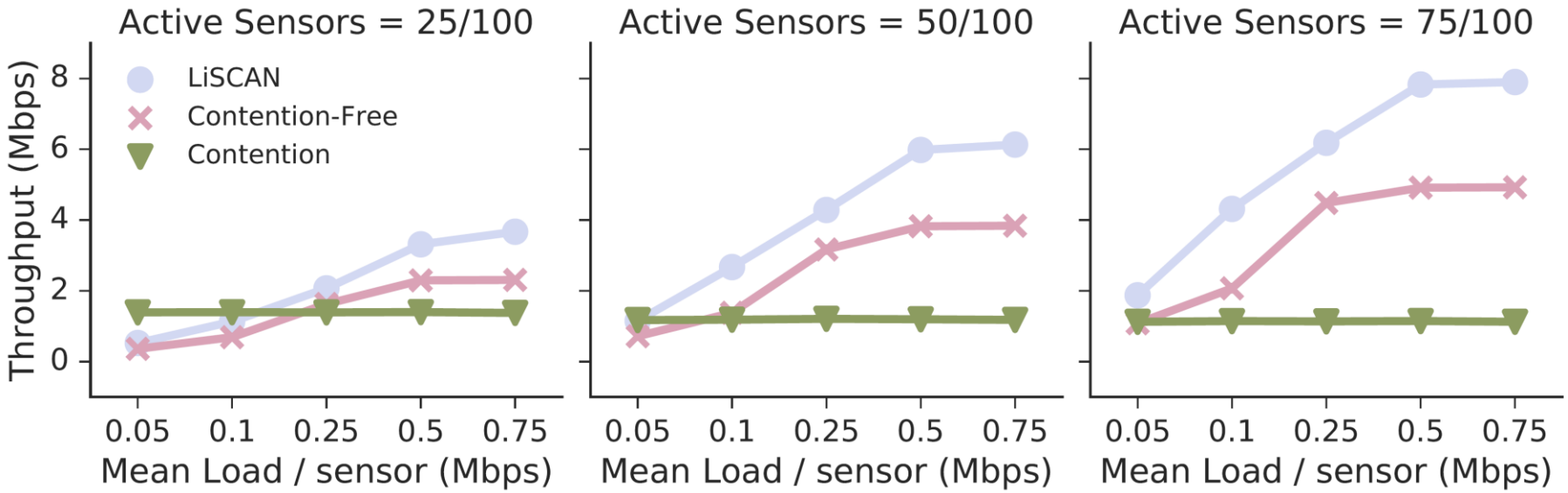
- Protocols
  - LiSCAN, Contention-based radio access and Contention-free radio access
- Sensor traffic model
  - Poisson Pareto burst process
  - 10ms mean burst time length with varying burst arrival rate (**Mean offered load/ sensor**)
  - Maximum of 100B packet aggregation
- Network
  - 100 sensors with varying fraction of sensors generating traffic (**Active sensors)**
- Polling
  - Randomized round-robin mechanism
- Energy Consumption
  - Typical sensor energy consumption states

Energy Consumption



- In contention-based strategy, negligible increase in transmission due to heavy traffic load
- Contention-based strategy
  - Transmission time increases with offered load before saturation
  - Transmission time per sensor decreases with increase in number of active sensors
- LiSCAN provides 5X reduction in energy consumption
  - Radio awake only for data transmission
  - Consumption by VLC wake-up receiver is comparable to radio module sleep state

Aggregate Throughput



- Low traffic
  - Polling overhead dominates performance in contention-free strategies
- Moderate-to-high traffic
  - LiSCAN's virtual full-duplex operation doubles data transmission time

Related Work

- Hybrid VLC-RF WLANs
  - LiRA WLAN: VLC downlink data transmissions with triggered ACK over RF [1]

In contrast: VLC polling with RF data in uplink from sensors

- Low power radio
  - Active wake-up receiver sharing energy with sensor [2,3]

In contrast: Energy autonomous VLC wake-up in LiSCAN for asynchronous traffic

- Asynchronous energy-saving MAC protocols
  - Do not eliminate radio channel sensing

In contrast: In LiSCAN, radio awake only for data transmission

[1] S. Naribole et al., “LiRa: a WLAN architecture for Visible Light Communication with a Wi-Fi uplink” *IEEE SECON*, 2017
[2] J. Dias et al., “Green wireless video sensor networks using FM radio system as control channel” *IEEE WONS*, 2016.
[3] D. Deng et al., “IEEE 802.11ba: Low-Power Wake-Up Radio for Green IoT,” *IEEE Communications Magazine*, July 2019.

LiSCAN

RICE

Architecture

- VLC and Wi-Fi integrated at the MAC layer
- Single layer-2 interface

Protocol

- Pre-emptive Interference Avoidance
- Pipelined polling with ACK over VLC

Evaluation

- Implemented LiSCAN protocol in ns-3
- Reduces energy consumed and improves throughput