**LCA**

Easy-Flow:
Comparing and integrating Wireless and PLC Medium Access Control Protocols.

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Home and Building Automation Today

❏ High-end market, mainly for security and comfort.

❏ Not well suited for client/server mode, low rate (~10 kb/s)

Conventional Meter

IPv4

IPv4 gateway
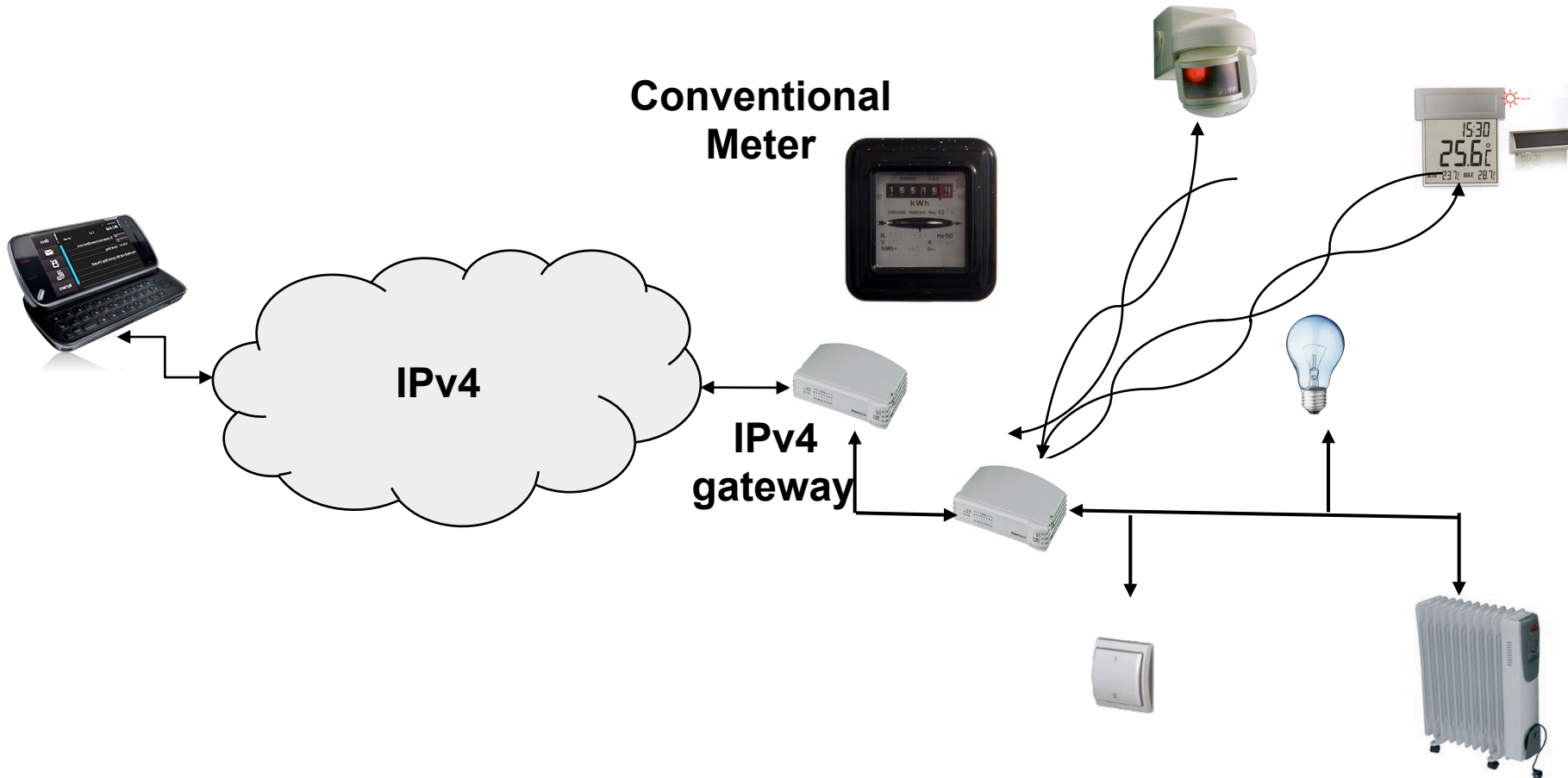
Home and Building Automation Tomorrow

❏ Global market, for security, comfort and energy savings.

❏ Low-power, low-cost, higher rate (100's Mb/s)

❏ Hybrid wireless (RF) and power line (PLC) communications.

Smart Meter, Energy Hub

IPv4/IPv6
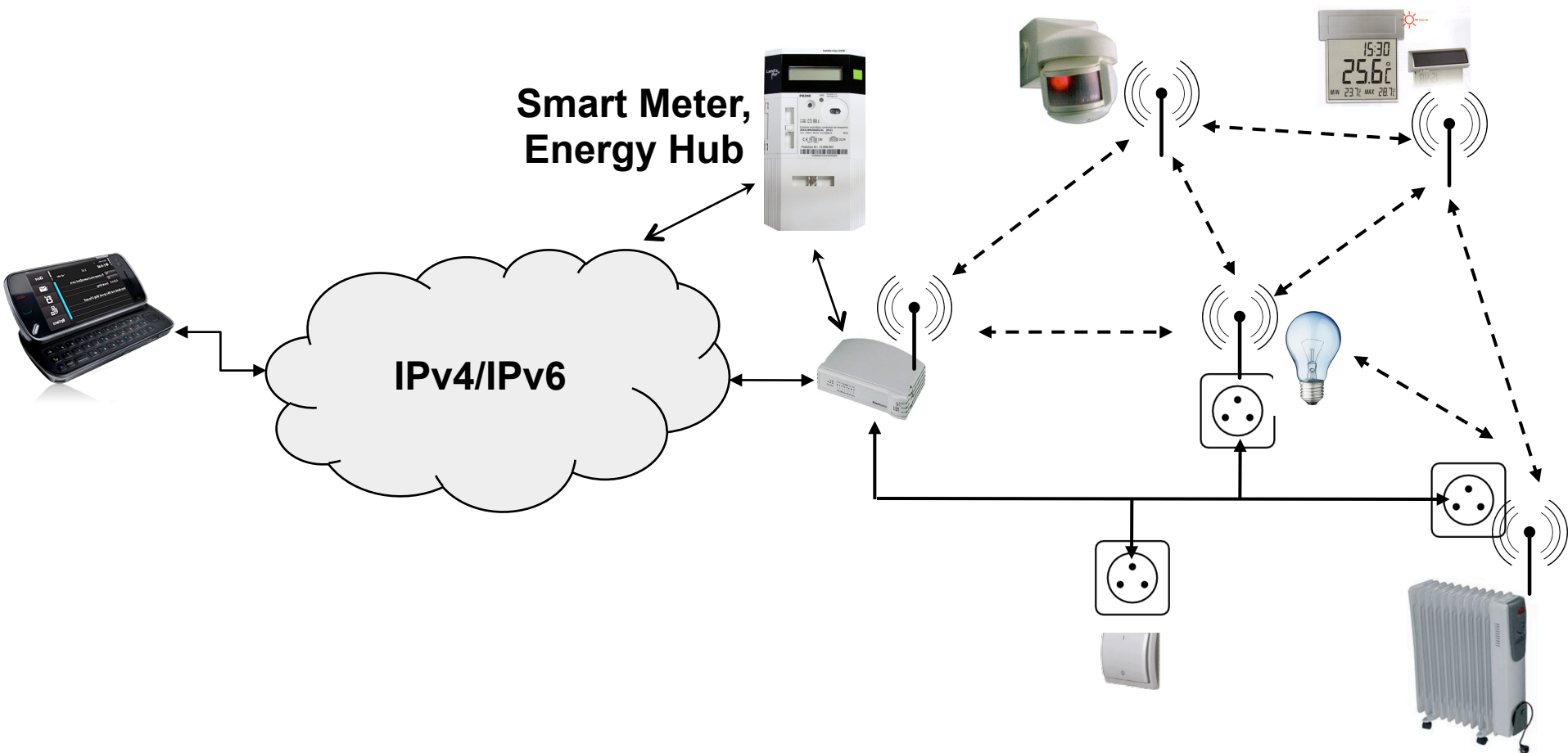
Multi-hop hybrid networks: Wifi with PLC

❏ Hybrid wireless (RF) and power line (PLC) communications.

❏ High Rate (Security, Streaming)

❏ Low Rate (Energy Saving, Comfort)
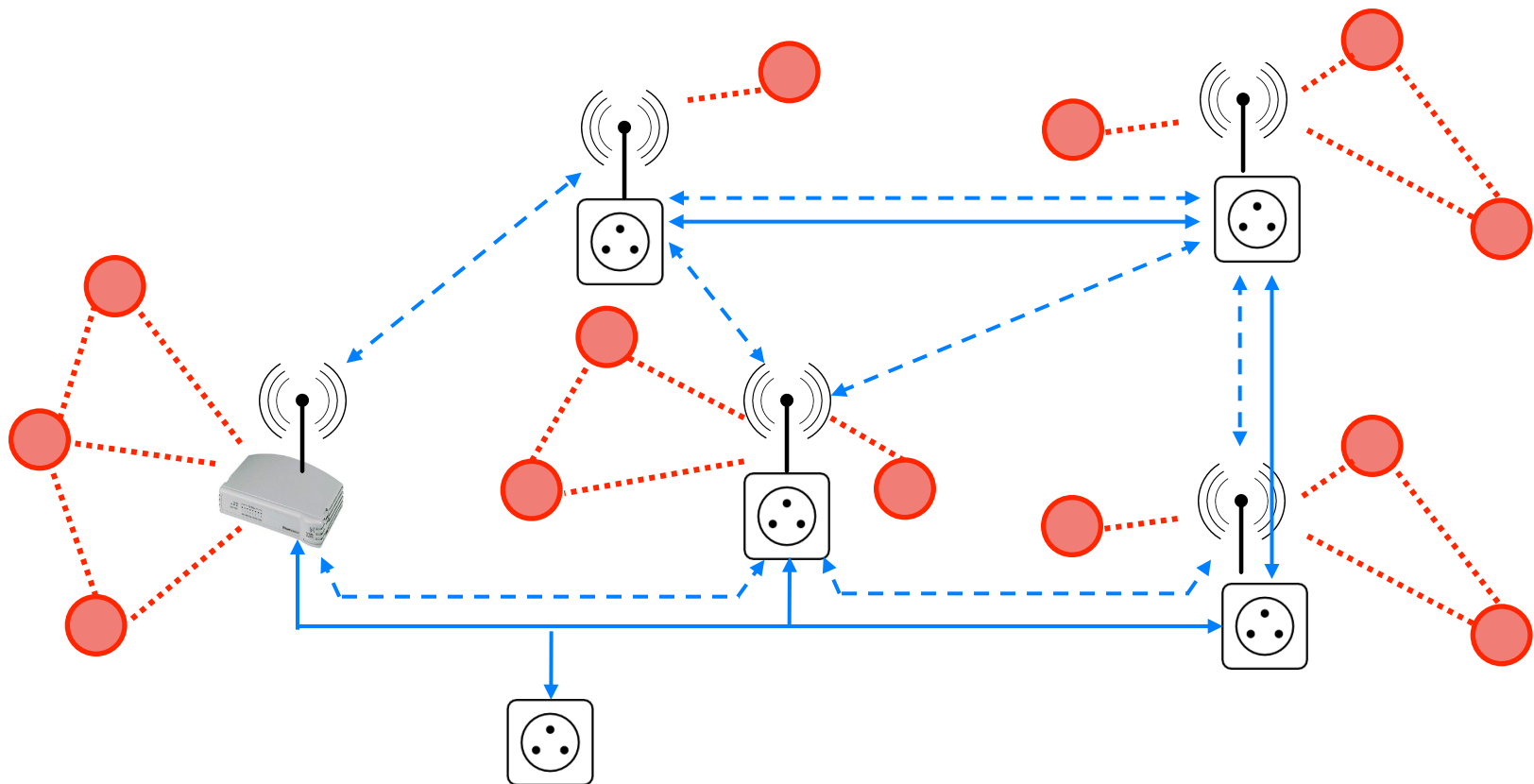
Hybrid PLC-RF Home Networks

	Wireless (RF)	Power Line Com. (PLC)
High Rate (EPFL)	IEEE 802.11	IEEE 1901
Low Rate (HEIG Vd, HES-Fr)	IEEE 802.15.4	Homeplug C&C: fading away -> HomePlug GreenPHY (similar to IEEE 1901)

Hybrid PLC-RF Home Networks

	Wireless (RF)	Power Line Com. (PLC)
High Rate	**IEEE 802.11**	**IEEE 1901**

1. **IEEE 802.11 vs IEEE 1901**
2. **IEEE 802.11 with IEEE 1901**

High Data Rate CSMA MACs: Wifi vs PLC

❏ Wireless (RF): **IEEE 802.11** well studied both in single hop and multi-hop networks

- > 240000 entries on scholar.google for "IEEE 802.11 + wireless".
- Throughput: computed with high precision using Bianchi's model
- Fairness: known in single-hop (fair) and multi-hop (unfair)

❏ Power Line (PLC): **IEEE 1901** little studied both in single hop and multi-hop networks

- < 1000 entries on scholar.google for "IEEE 1901 + PLC").
- Some early work on throughput, but little known.
- Fairness is unknown

Fairness of 802.11 Wifi vs 1901 PLC

❏ Both protocols are CSMA based:
- Pick Contention Window CW and draw back-off BC in [0,CW].
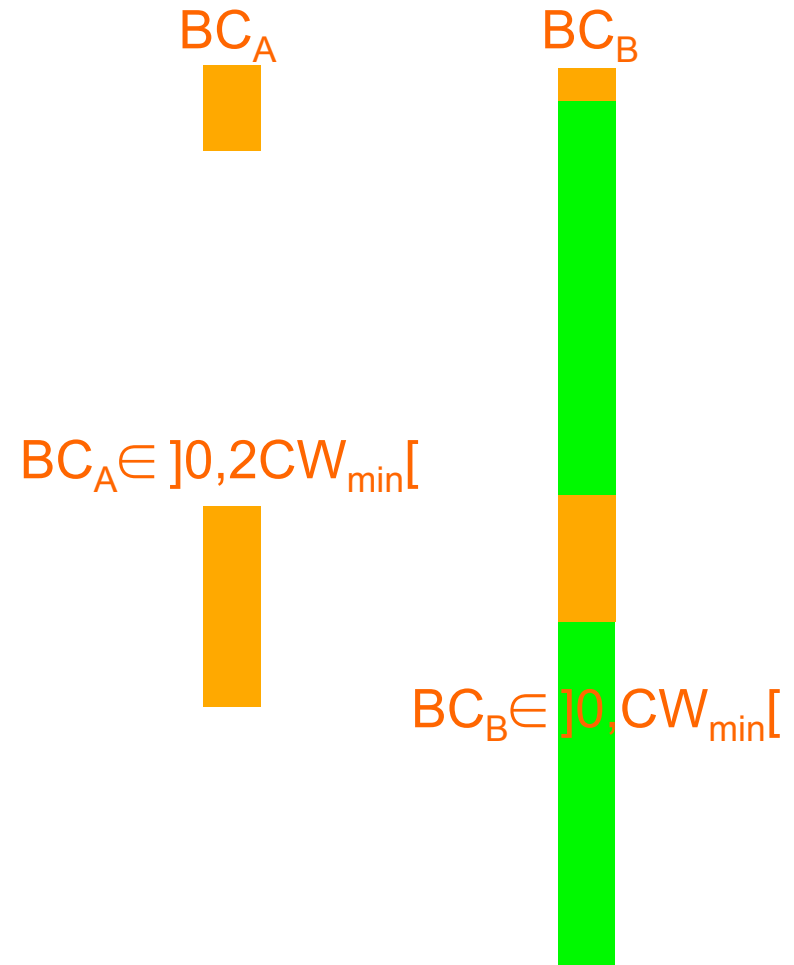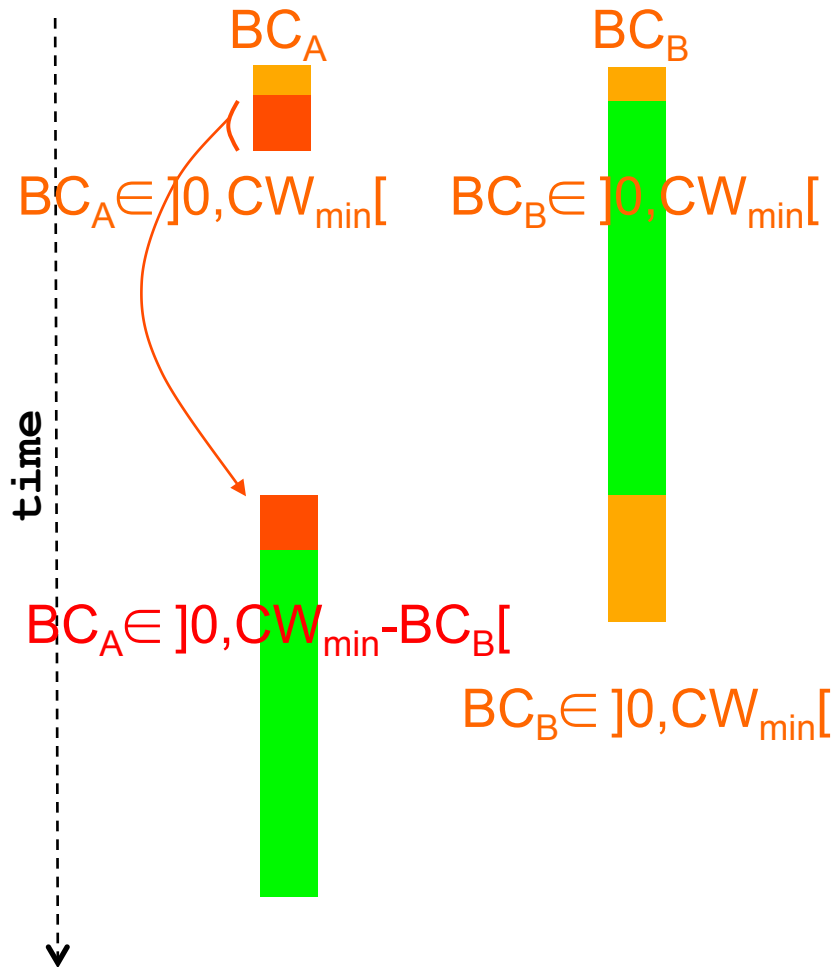- Decrement BC, transmit when BC = 0.
- If collision, then CW = 2CW.

❏ IEEE 802.11 is
- Conservative (large CW)
- "Simple" (only one counter BC)
- If medium sensed busy, BC frozen until medium sensed idle
- Only stations involved in a collision double their CW.

❏ IEEE 1901 is
- Aggressive (small CW)
- Complex (3 counters BC, DC, BPC)
- If medium sensed busy, then
  - If DC = 0, then CW = 2CW, select new DC ≥ DC (dep. on BPC), draw BC in [0,CW]
  - If DC ≠ 0, then decrement BC and DC
- After a collision, all stations involved in collision and with DC = 0 double their CW.
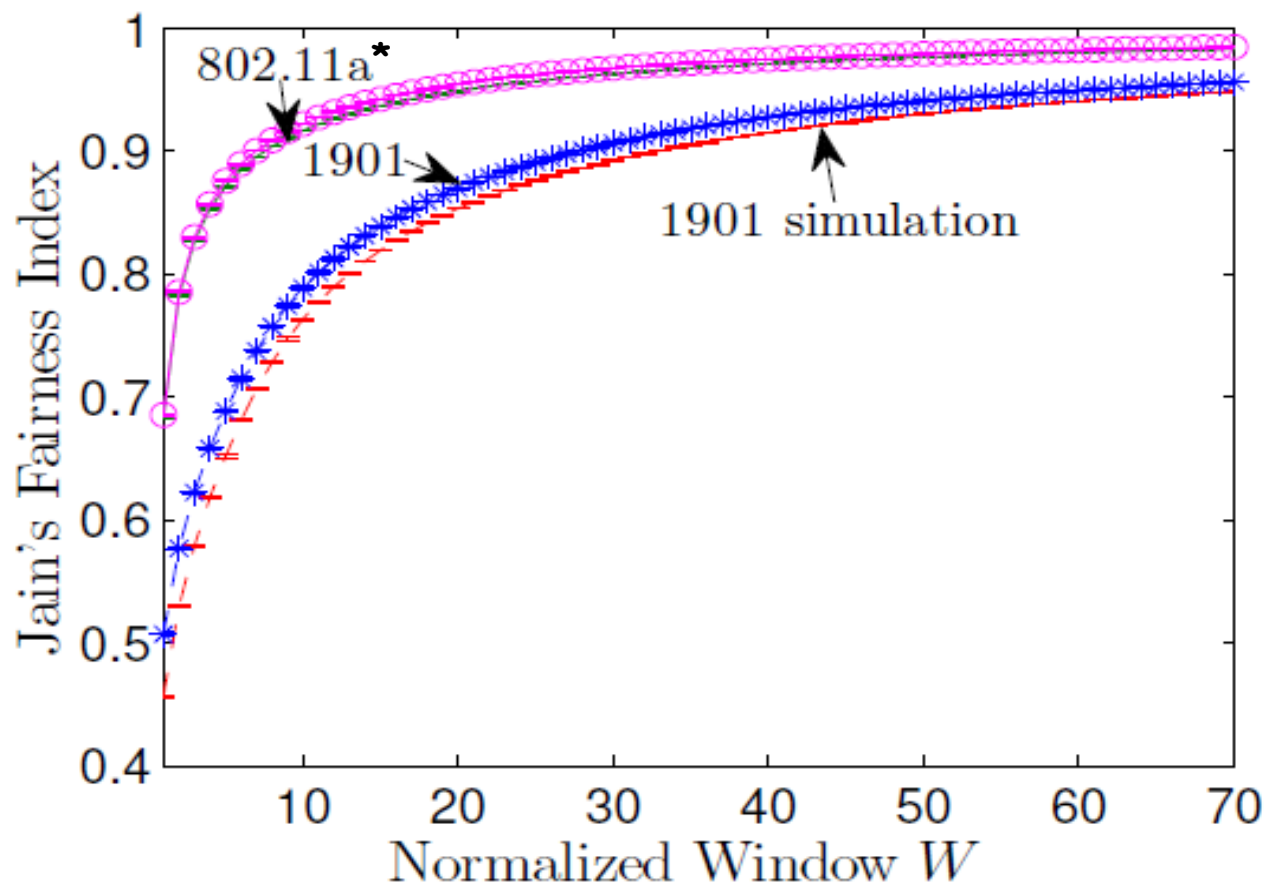
Which is fairer: Wifi or PLC?

BC_A

BC_B

BC_A

BC_B

$BC_A \in]0, CW_{min}[$

$BC_B \in]0, CW_{min}[$

time

$BC_A \in]0, CW_{min} - BC_B[$

$BC_B \in]0, CW_{min}[$

$BC_A \in]0, 2CW_{min}[$

$BC_B \in]0, CW_{min}[$

Fairness of 802.11 Wifi vs 1901 PLC

❏ Metric for evaluating (short-term) fairness:
  ● Jain's fairness index FI over window of *W* packets (0 ≤ FI ≤ 1: perfect fairness if FI = 1).
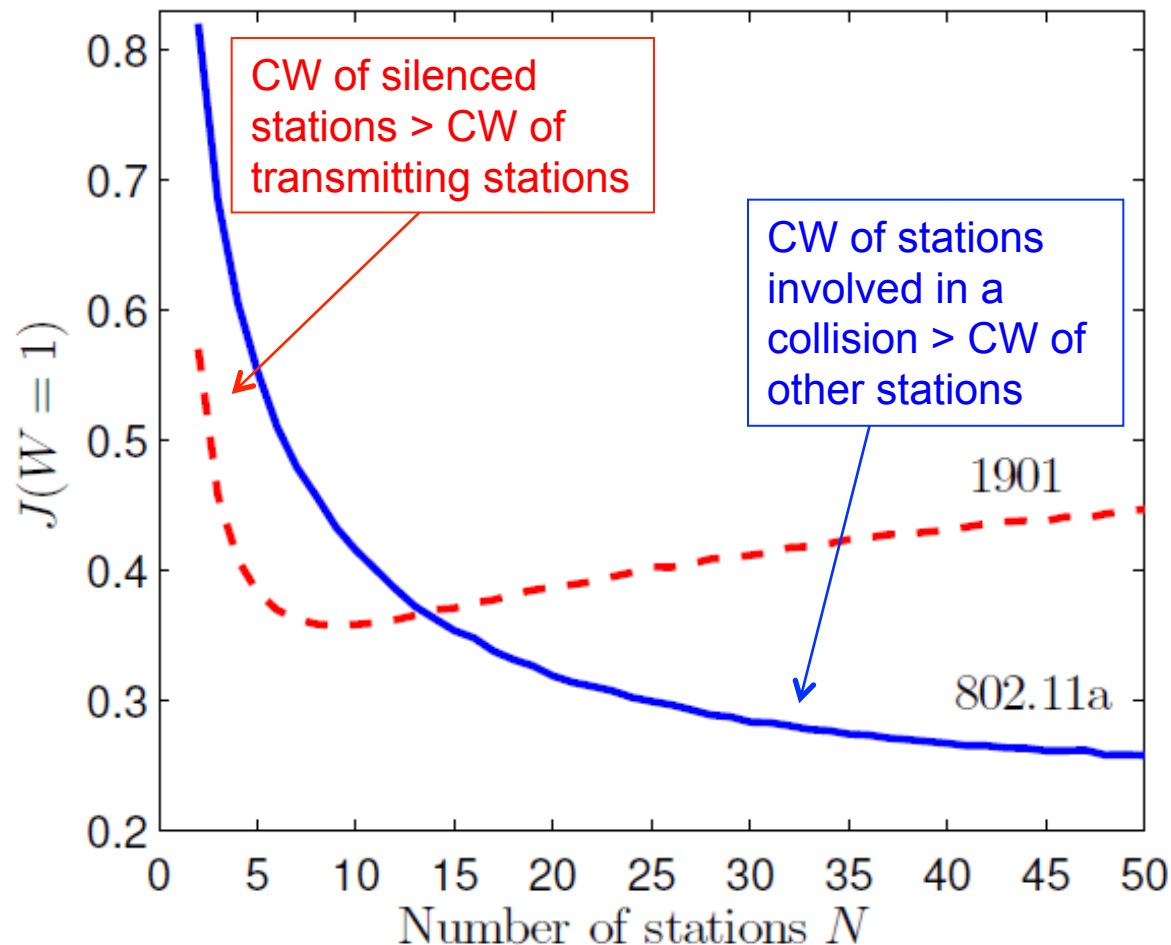
*simulation and test-bed results

N = 3 stations

Fairness of 802.11 Wifi vs 1901 PLC

❏ Metric for evaluating (short-term) fairness:
- Jain's fairness index FI over window of *W* packets (0 ≤ FI ≤ 1: perfect fairness if FI = 1).

CW of silenced stations > CW of transmitting stations

CW of stations involved in a collision > CW of other stations
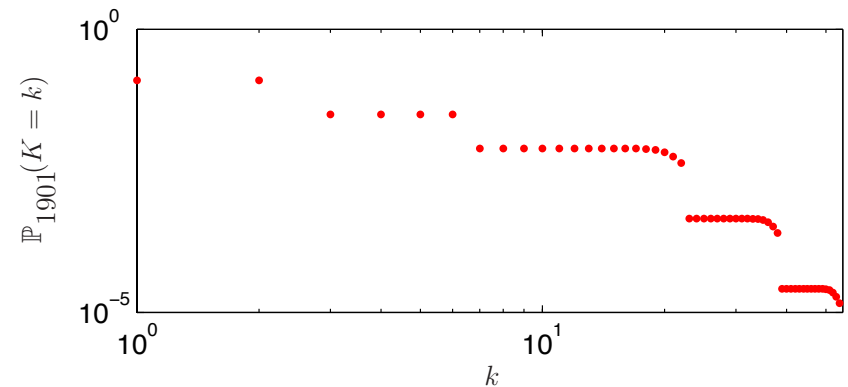
1901

802.11a

Fairness of 802.11 Wifi vs 1901 PLC

❑ Metric for evaluating (short-term) fairness:

● Number K of packets between two consecutive packets sent by the same station (perfect fairness if K = N-1 for N competing stations).

● Theorem: For N=2, K is short tailed for 802.11, and long tailed for 1901:

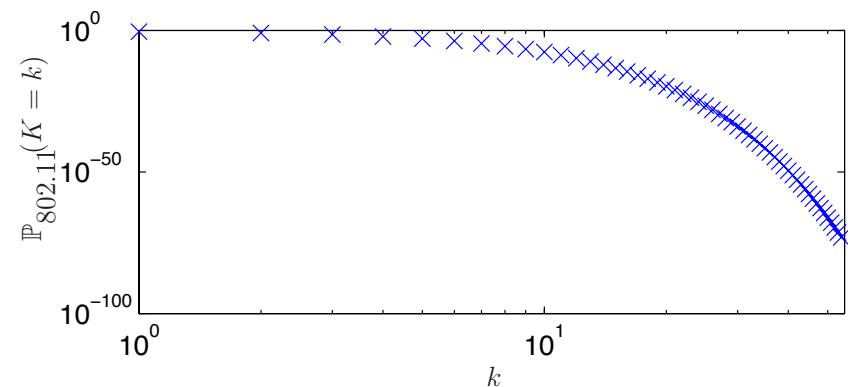$$P_{1901}(K > k) \,/\, P_{802.11}(K > k) \to \infty \text{ for } k \to \infty$$

❑ IEEE 1901:

P(K=k) computed in [VlachouHT13]
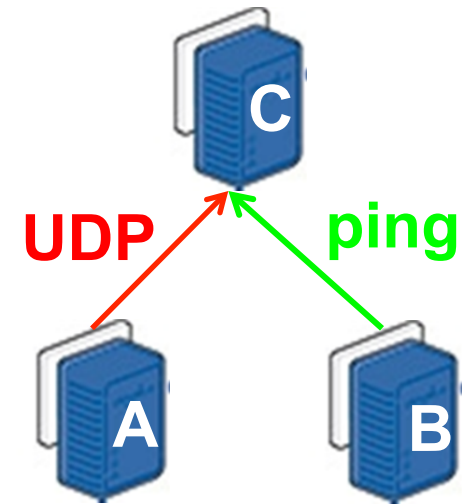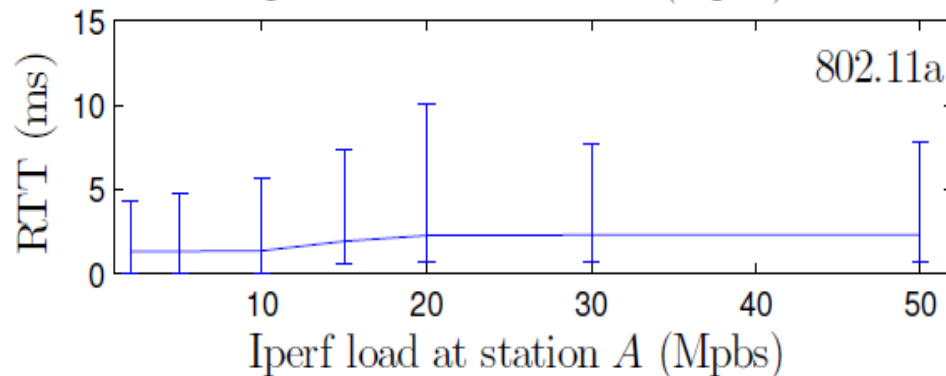
❑ IEEE 802.11:

P(K=k) computed in [Berger et al 04]

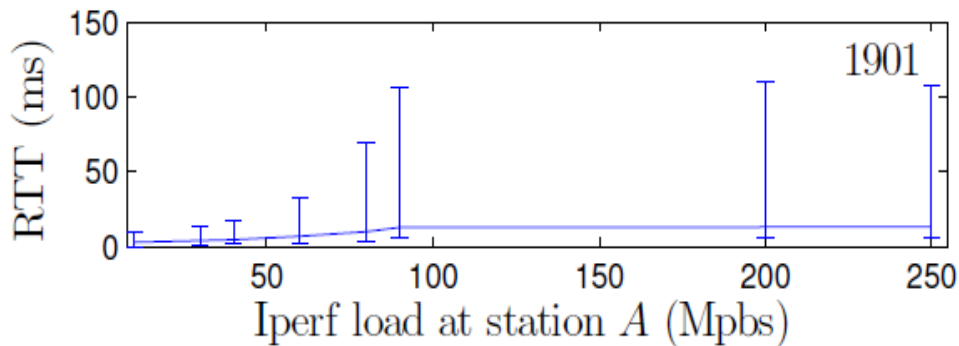# Effect on Delay

❏ Metrics for evaluating (short-term) fairness:
- Station A sends UDP traffic to station C.
- Station B sends ping requests to station C.

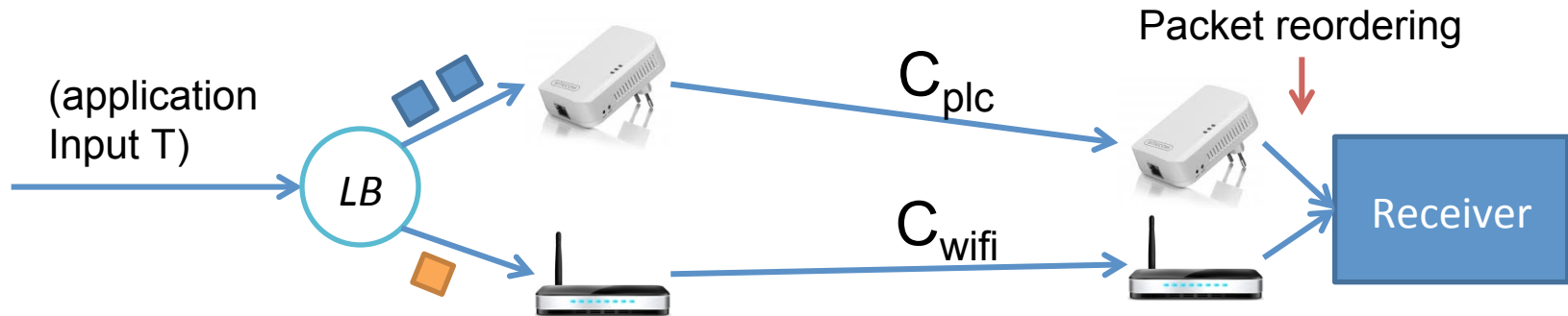❏ Median RTT of 10^4 requests of B as a function of load of A.

Multi-hop hybrid networks: Wifi with PLC

❏ Nodes have RF, PLC or dual PLC/RF interfaces.

❏ Offers increased throughput and robustness.

❏ Link aggregation between some nodes -> load balancing.

❏ Multiple paths between nodes -> routing.
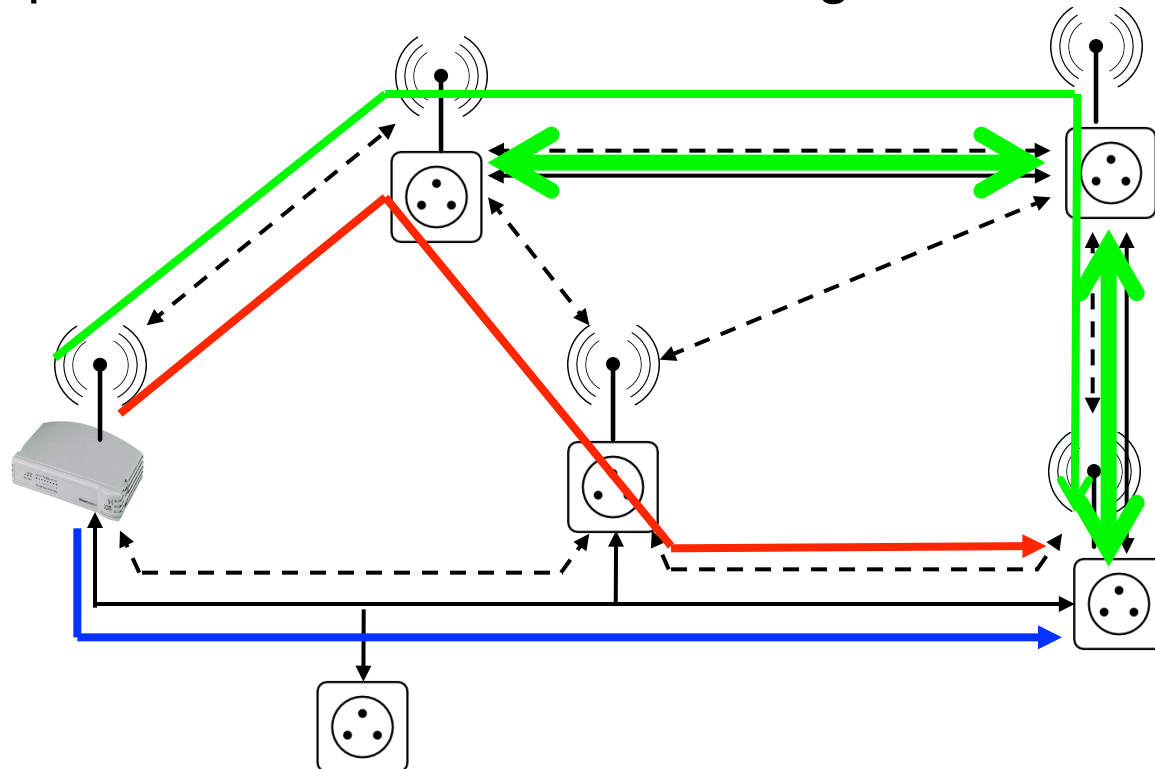
First step: Load balancing algorithm *LB*

- ❏ Dynamic load balancing because T, C_{plc} and C_{wifi} time-varying.
- ❏ First implementation with a Dynamic Weighted Round Robin
  - ● Capacity measured periodically,
  - ● Used to compute weights.

Hybrid PLC-RF Home Networks

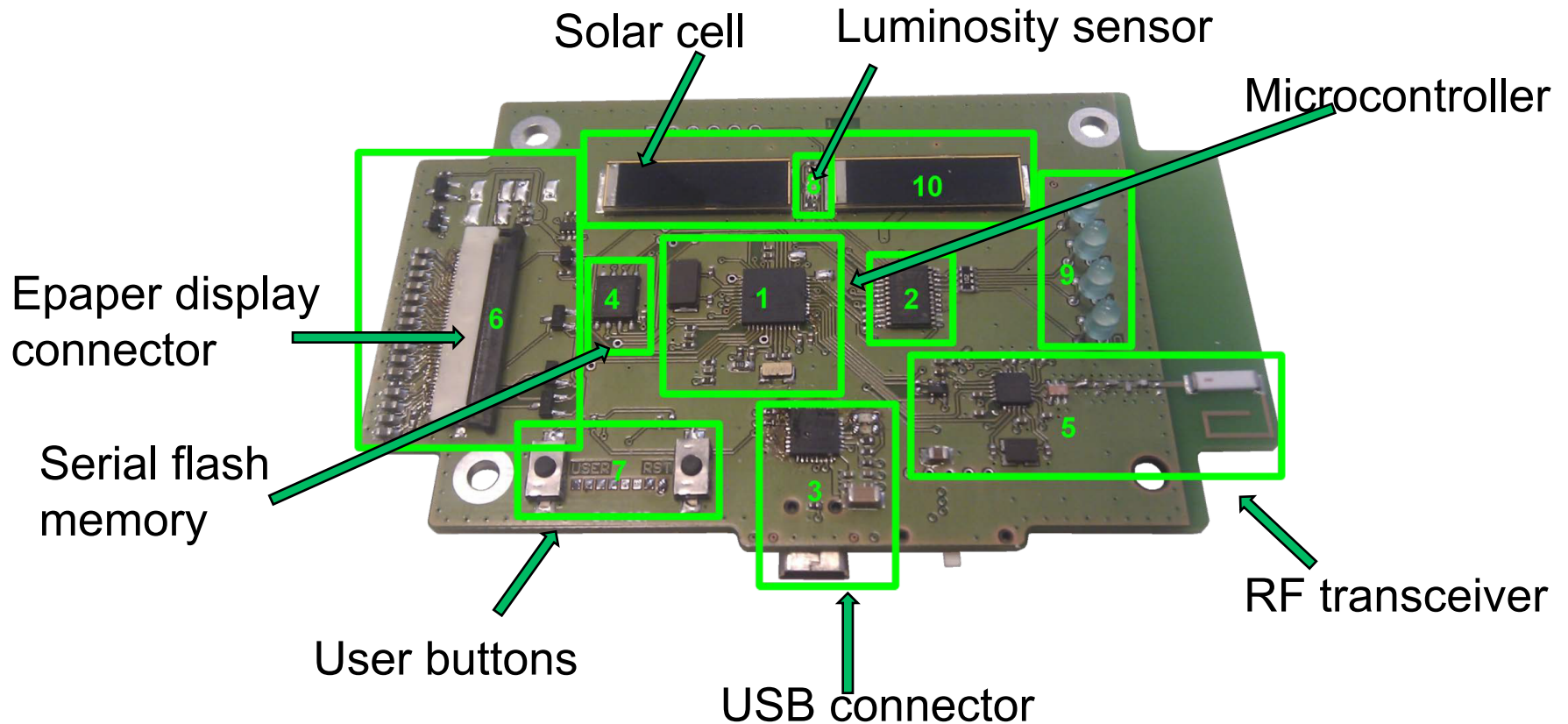|	Wireless (RF)	Power Line Com. (PLC)
Low Rate	**IEEE 802.15.4**	

IEEE 802.15.4 Devices: Smartlabel

RF Modems for 802.15.4

❏ A custom LR RF device has been built : SmartLabel

❏ Uses 802.15.4 technology with sub-1GHz capabilities allowing frequency diversity of LR network with respect to 802.11 2.4GHz bands in HR network.

❏ Ultra-low power

❏ Similar to state-of-the-art Tmote Sky nodes with in addition :

- extended memory ressources allowing implementation of OS kernels more powerful than Contiki (from 48kbits to 128kbits),
- ultra-low power epaper passive screen allowing versatile applications,
- solar cell with energy harvesting capabilities.

RF Modems for 802.15.4

Solar cell
Luminosity sensor
Microcontroller
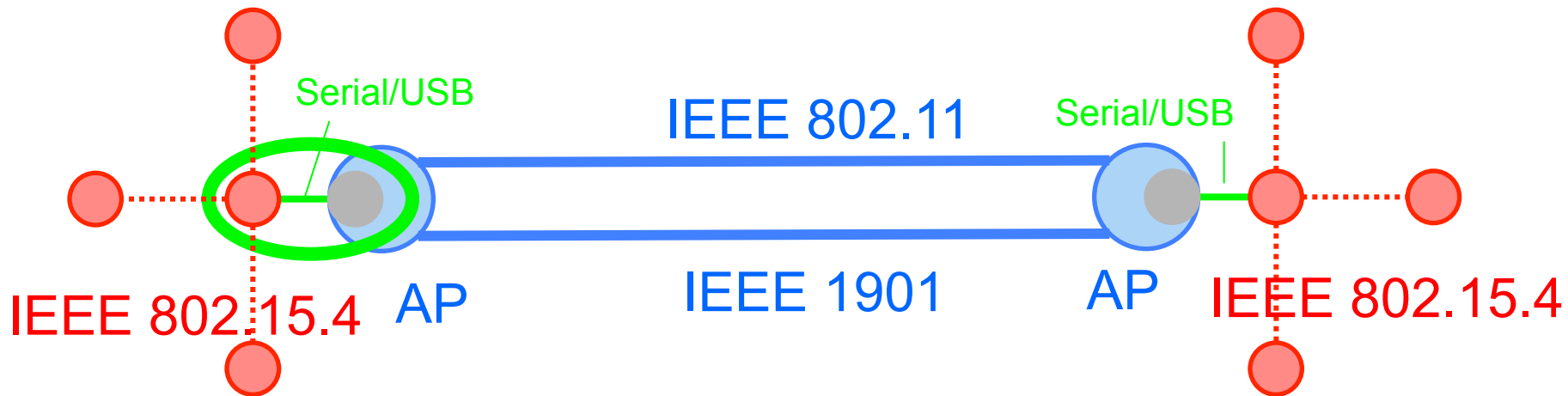Epaper display connector
Serial flash memory
User buttons
USB connector
RF transceiver

Features
- E-ink 2-inch 200x96 pixels display
- IEEE 802.15.4 / 868MHz
- Battery powered (for bootstrap)
- 7 working prototypes

Interfacing HR with LR

❏ AP to HR network are extended using a SmartLabel as a bridge between HR network and LR network.

❏ Bridge configured to forward packets from the AP to the LR network and vice versa.

❏ The configuration is made by the AP side software through a USB connection using Service Location Protocol.

Subscription of Smartlabels to LR network
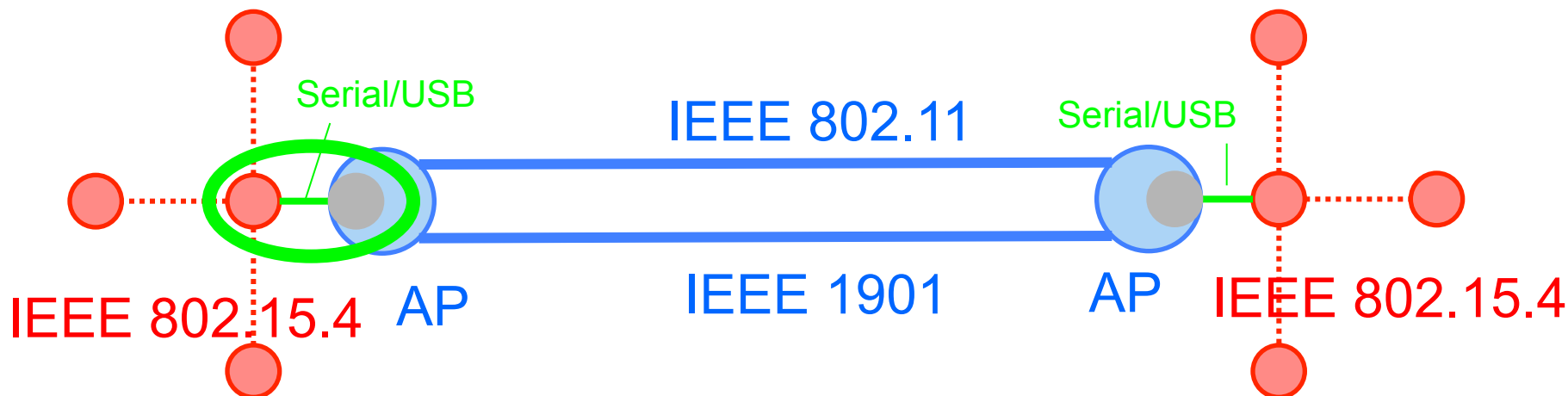
❑ Each SmartLabel in the RF range of that access point is now able to subscribe to that LR network following a standard three-way handshake.

Interfacing HR with LR
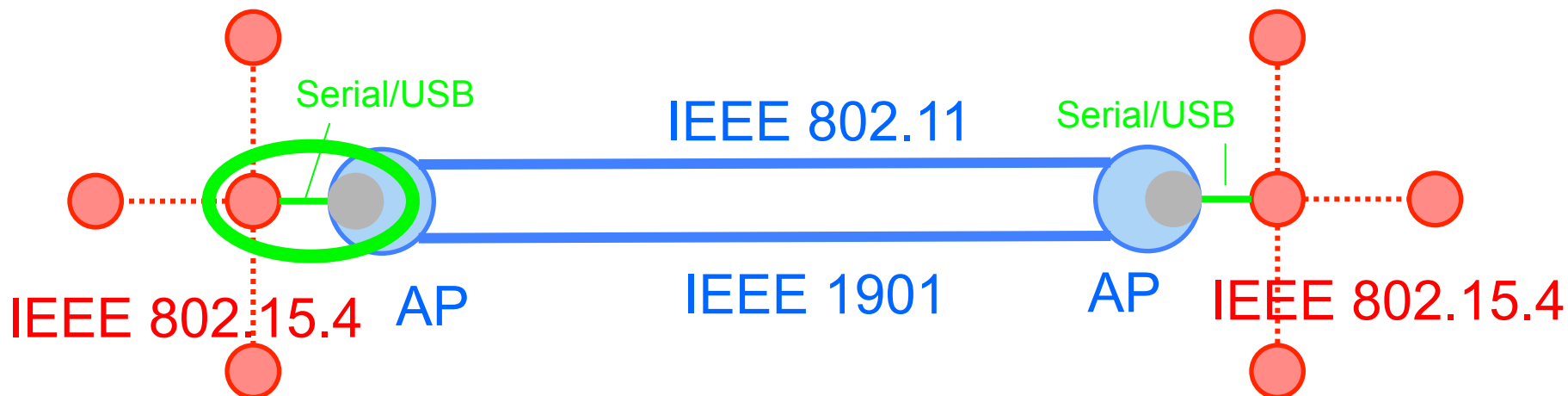
❏ Next steps:

- IEEE 802.15.4: have a first version of own motes in which we can implement a 6LoWPAN technology (i.e light IP stack).

- Prepare the ground for the development of a gateway in which we will embed the three technologies (IEEE 802.11, P1901 and 802.15.4) plus the load balancing technology for HR network.

Hybrid PLC-RF Home Networks

	Wireless (RF)	Power Line Com. (PLC)
High Rate (EPFL)	IEEE 802.11	IEEE 1901
Low Rate (HEIG Vd, HES-Fr)	IEEE 802.15.4	

Demonstration

IEEE 802.11

IEEE 1901

AP

AP

IEEE 802.15.4

IEEE 802.15.4
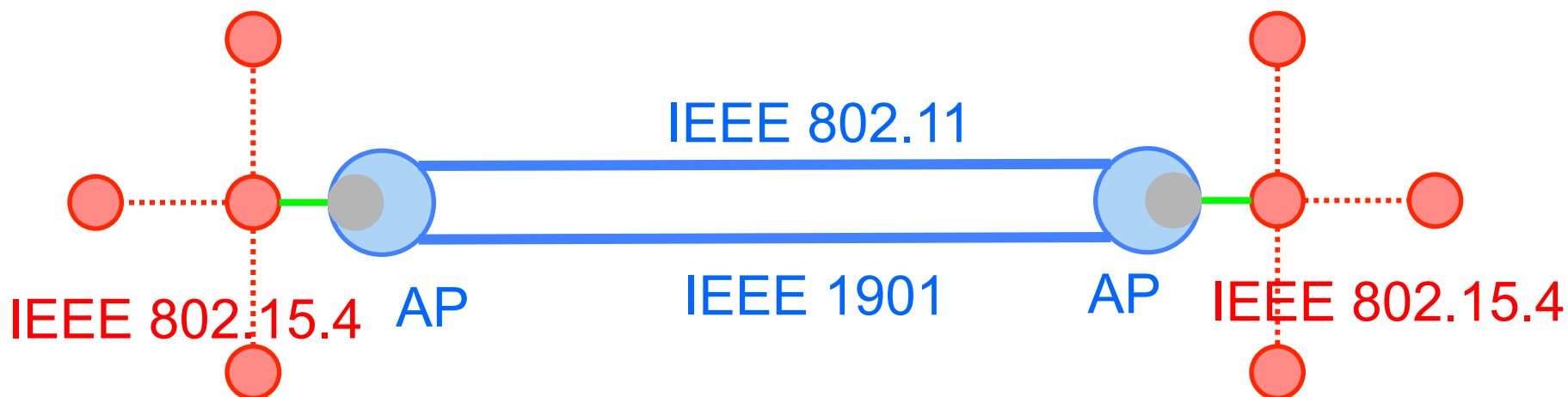
❑ Two goals:

- High rate: What throughput can we achieve with dual PLC/RF links (802.11 + 1901)?
- Low rate: Extend the access point capabilities w.r.t. sub1-GHz technology and test the accept point functionality.

Conclusion

❏ High Data Rate:

- IEEE 1901 is less fair than IEEE 802.11 for N < 15 stations; it is particularly unfair for N = 2 stations [VlachouHT13].
- Verified analytically (N=2), by simulations and testbed experiments.
- First step towards hybrid, high rate networks: Load balance between RF running 802.11 and PLC running 1901.
- Next step: routing for multi-hop Hybrid Networks running 802.11 and 1901.

❏ Low Data Rate:

- SmartLabel, LR RF device running on IEEE 802.15.4, has been built
- Ultra-low power devices with sub-1GHz transceiver for frequency diversity w.r.t. 802.11 technology
- Protocols for discovery and detection of AP.
- Next step: IEEE 802.15.4 with 6LoWPAN technology; prepare the ground for the development of a gateway in which we will embed the three technologies (IEEE 802.11, P1901 and 802.15.4).

Next step: MAC + Routing for Hybrid Networks

Devise routing + MAC schemes that...

❏ ... exploit diversity (HR network)

- ● RF nodes and links
- ● PLC nodes and links.

❏ ... under the constraint of time varying and unreliable channels:

- ● PLC: switching of power devices,
- ● RF: fading and multi-path effects.

❏ … integrate at APs

- ● 802.11, 1901 and 802.15.4.

❏ ... save energy (LR network)

- ● RF nodes: ultra-low power.