ERICSSON

FUTURE RADIO ACCESS

IMPLEMENTATION & DEMONSTRATION

SCANDINAVIAN WORKSHOP ON TESTBED-BASED WIRELESS RESEARCH

NOVEMBER 27TH 2013

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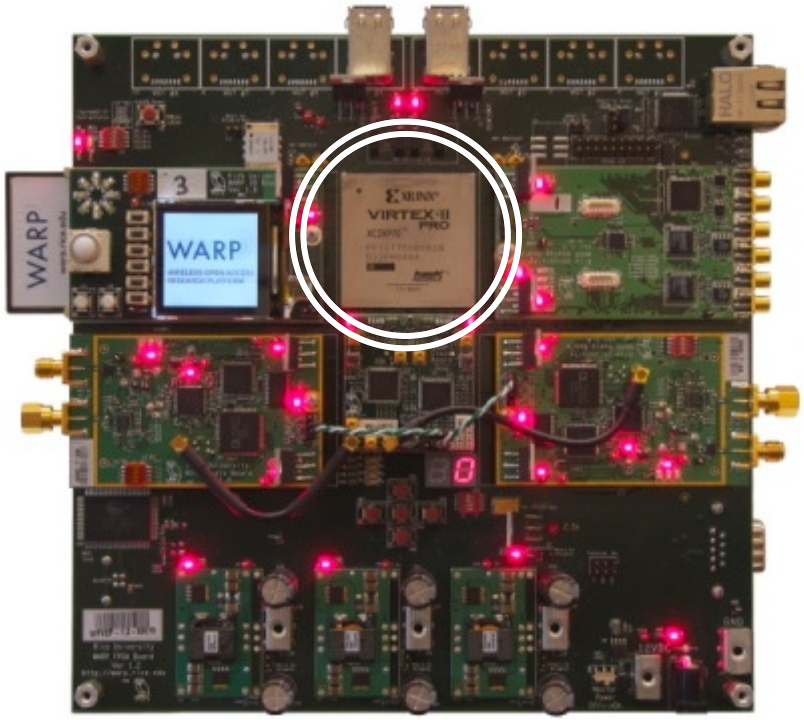
GOAL

"To study and investigate new wireless communications mechanisms via prototyping and proof-of-concept"

CONTENT

PLATFORM: WARP BOARD

- *http://warp.rice.edu*
- Off-the-shelf wireless prototyping kit
- RICE support: reference design
- Online community support
- Ethernet interface, ISM-band radio
- “Dumb” electronics around a “smart” FPGA (Xilinx Virtex II Pro)



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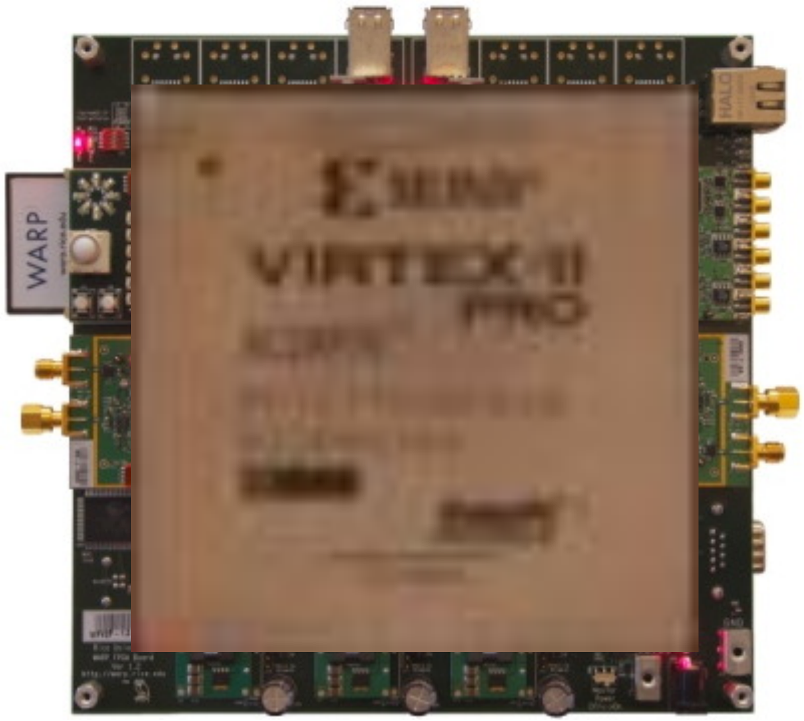

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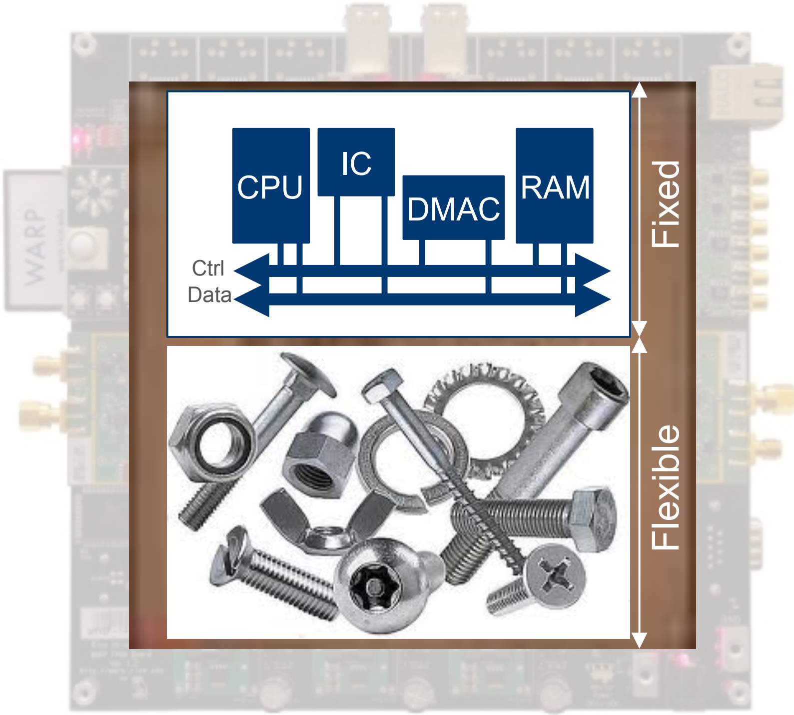
- FPGA:
  - "fixed" portion: PC-like
  - "flexible" portion: PC's peripherals (pcores)



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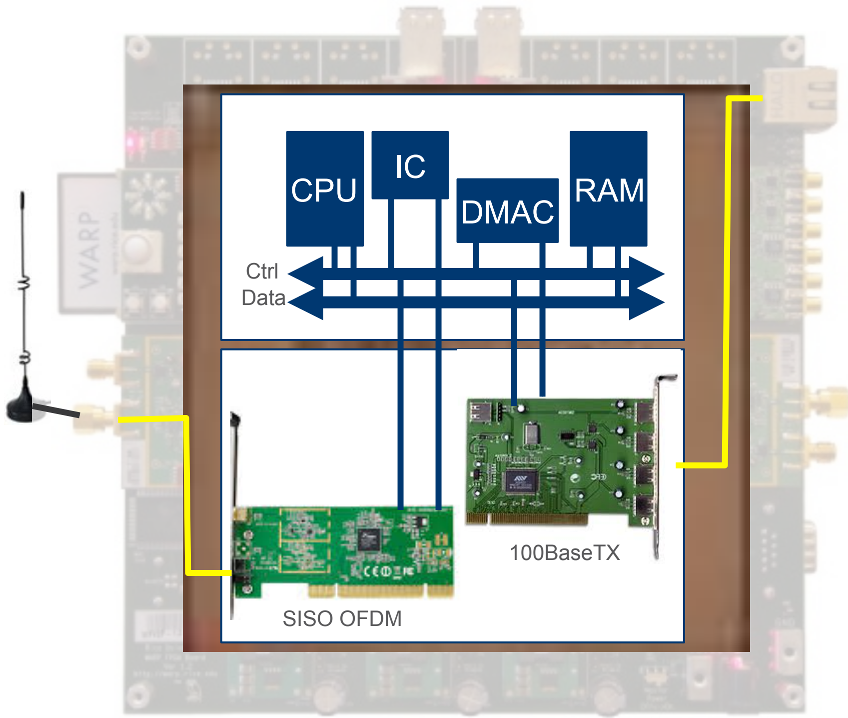
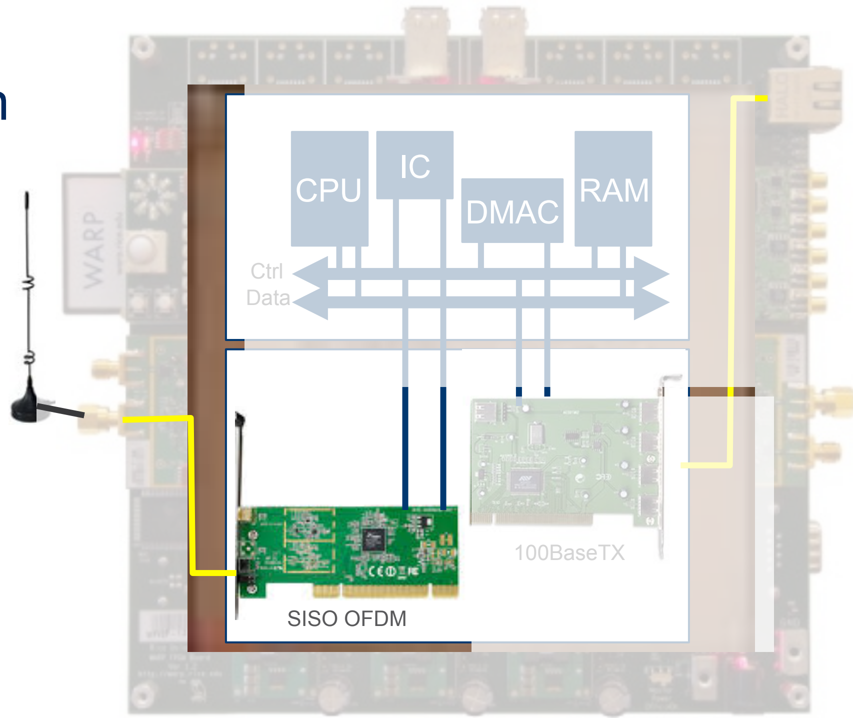
- “Dumb” electronics around a “smart” FPGA (Xilinx Virtex II Pro)
- FPGA:
  - “fixed” portion: PC-like
  - “flexible” portion: PC’s peripherals (pcores)
- Build **pcores** with the “flexible”, write C code to run on the “fixed” to interact with pcores



HARDWARE: PCORE

SISO OFDM

- Home-grown: developed together with our university partners @ UCSD
- Single OFDM radio, 4MHz bandwidth, ISM band operation (MAX2829 chip)



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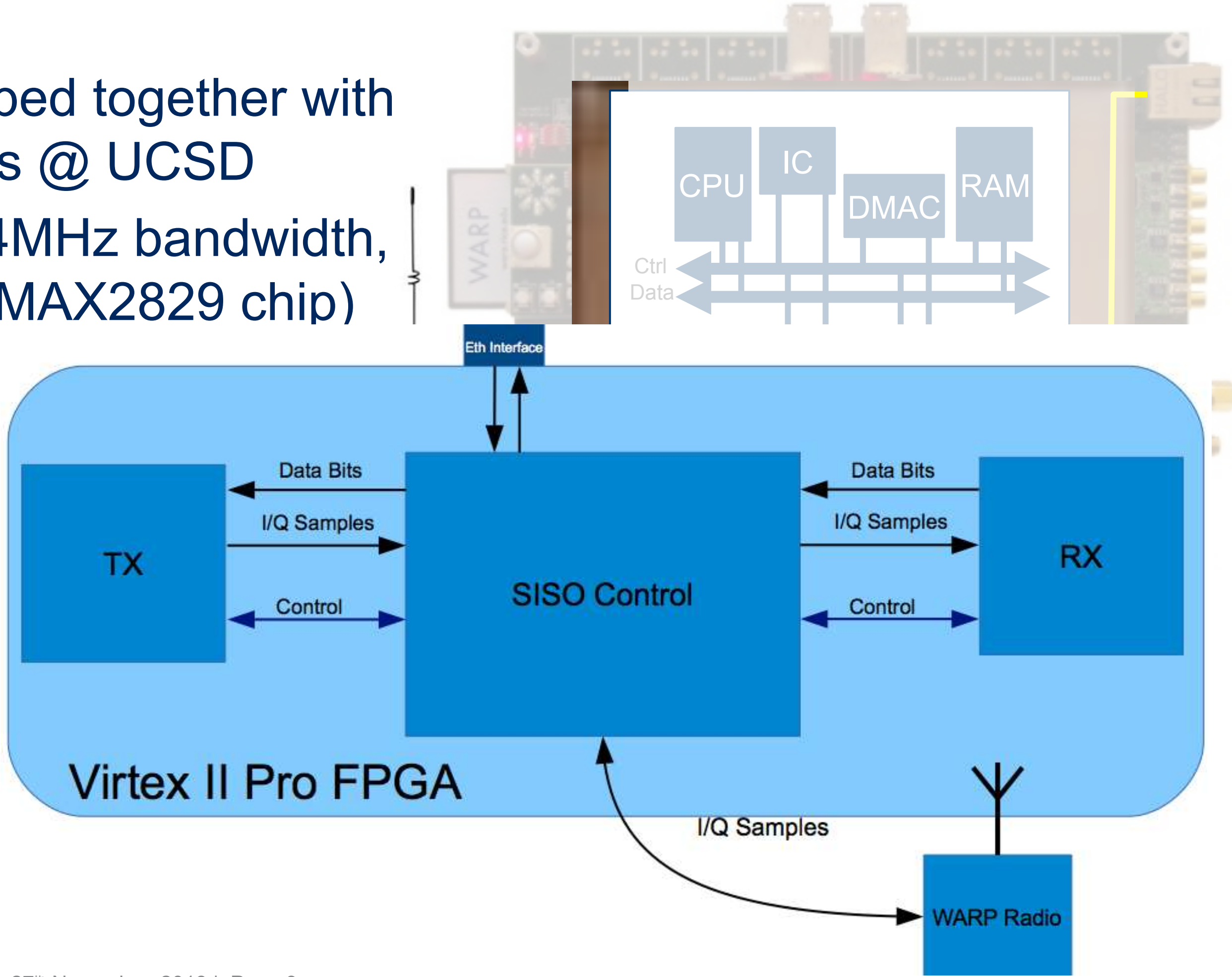

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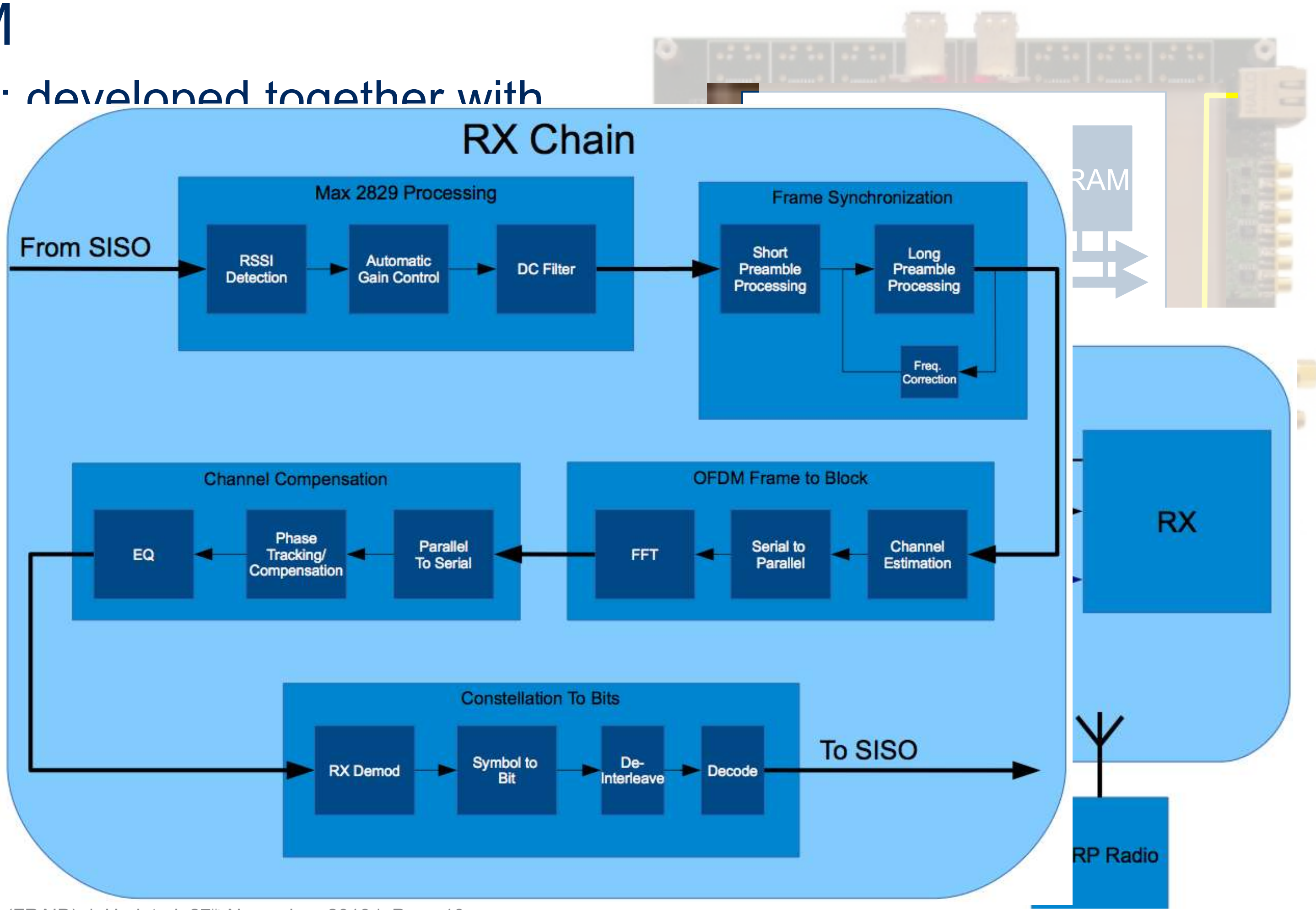
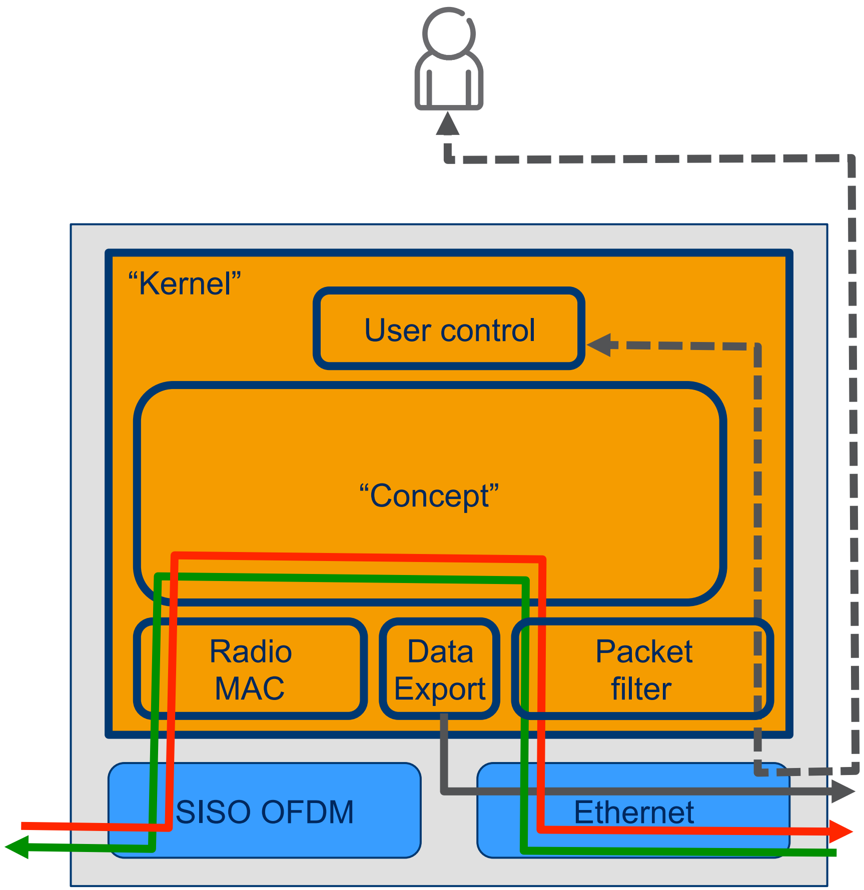


SOFTWARE: ELEMENTS

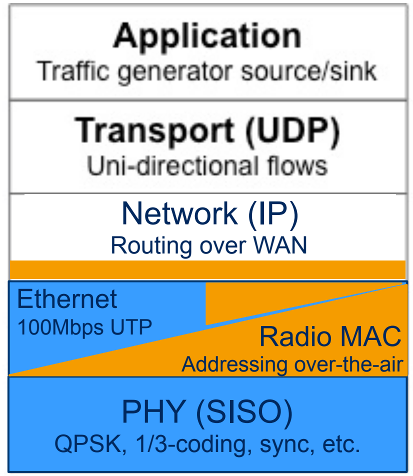
- Home-grown: mainly written in Kista (embedded programming, C)
- Low-level protocols:
  - Radio MAC: addressing and power-control
  - IP/ethernet for wired communications
- Layer-2 bridge: SISO OFDM–ethernet
- Control modules for interacting with running board, changing configuration on-the-fly
- Same software on all nodes (differentiation via DIP switch)
- Support modules for data export (i.e., for logging, visualization, etc.)



REAL-WORLD: NODES

- WARP board = Layer-2 ethernet bridge:
  - Wireless SISO OFDM ←→ wired 100BaseTX
- Tether WARP-board to a FreeBSD PC via dedicated 100BaseTX ethernet
  - PC: higher layers
  - WARP board: lower layers
- Wireless node = PC + WARP board


The Wireless Node



The Protocol Stack

- Over-the-air wireless node-to-node IP communication possible!

REAL-WORLD: THE LAB

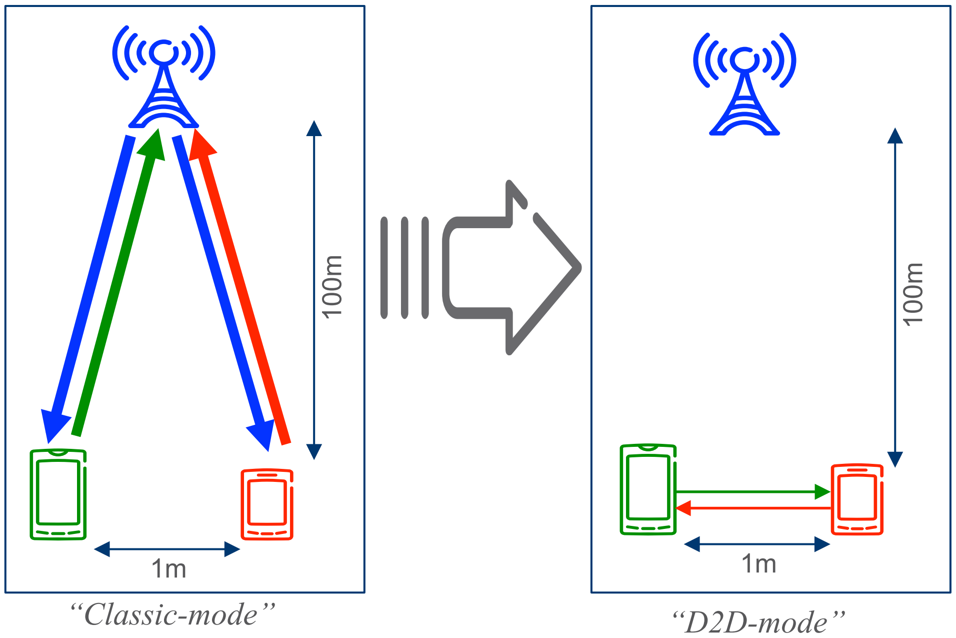
- Lab
  - Part of Ericsson Research, Wireless Access Networks
  - Located in Kista, Stockholm

CONCEPTS: TO-DATE

- Concepts demonstrated to-date:
  - Autonomous relay mechanism
    - In-between node auto-relays when SRC-DST endpoint communications fail
  - Uplink CoMP
    - UE uplink transmission detected by 2 BS
    - I/Q samples exchanged via BSs' ethernet backhaul and MRC-combined for better performance
  - RSSI sampler for Wi-Fi load studies
    - Estimate Wi-Fi 2.4GHz channel utilization based on RSSI values
  - Bi-directional network coding
    - Measurements of over-the-air XOR network coding behaviour
  - **Network-assisted device-to-device communications**

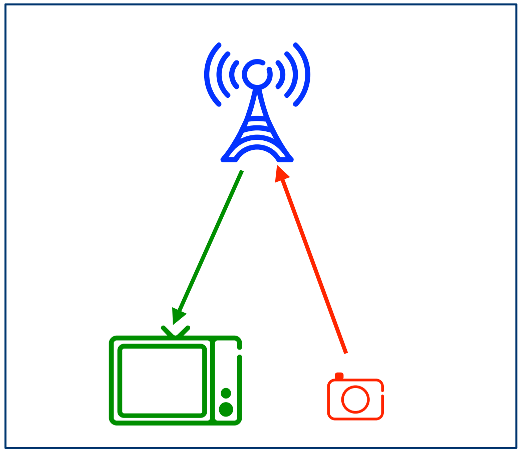
CONCEPTS: D2D

- Applies to devices in close proximity
- Exploit radio's natural broadcast characteristic
- Single-hop vs. multi-hop via the network
- Shorter distances ➔ lower transmit power
- Higher modulation/bitrates
- Offload network traffic
- General goodness overall!



CONCEPTS: NA-D2D

- Networked society: 50 billion **diverse** devices
  - Alarm clock awakens coffee maker
  - Washing machine notifies tumble dryer to warm up
- Advantages of “network-controlled”
  - Network is ubiquitous: works everywhere
  - “Zero” configuration - no need for SSIDs, WEP/WPA, “discoverable”, passkeys, etc.
  - Licensed spectrum operation
- DSLR–TV example: sequence of events
  - Communications commence in “classic” cellular manner
  - Network discovers endpoints are in close proximity
  - Endpoints are reconfigured, resources re-assigned
  - Benefits of D2D enjoyed!



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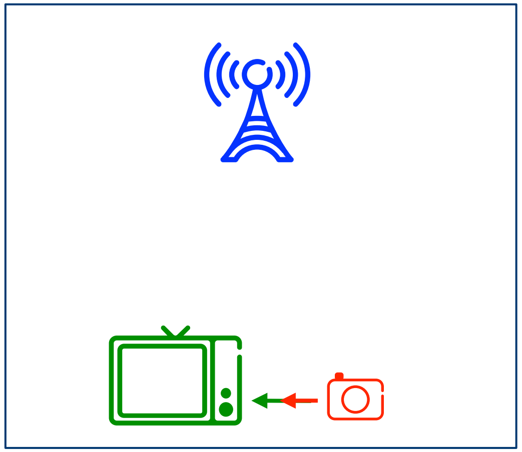
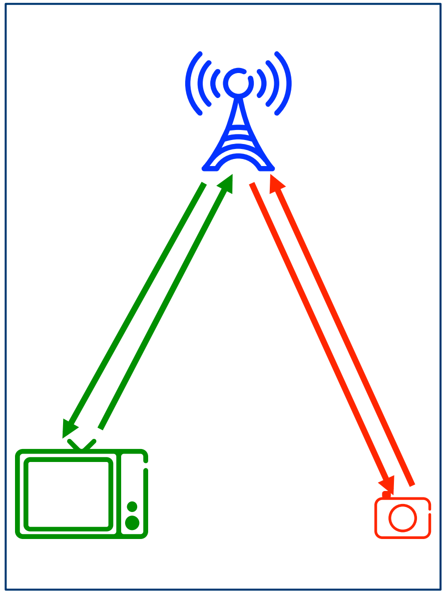
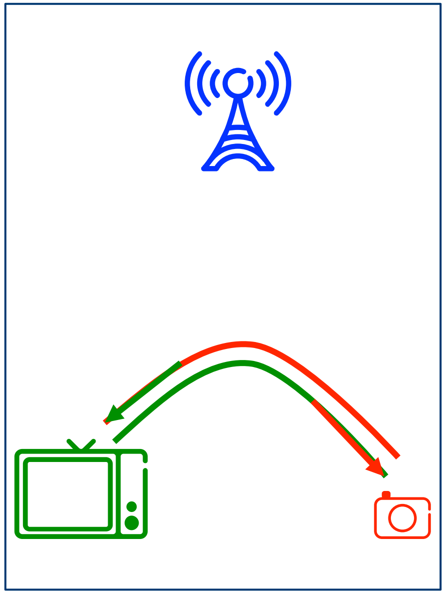


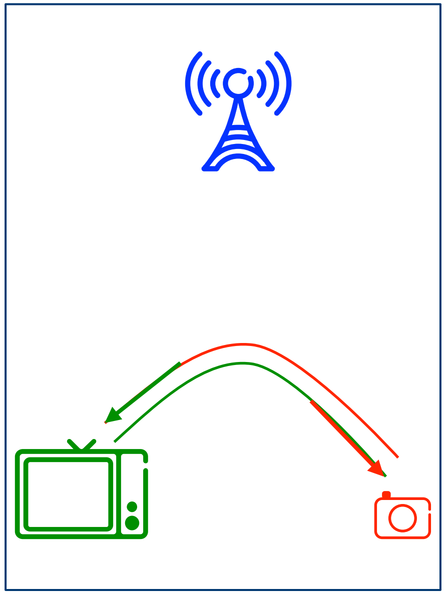
TIMELINE



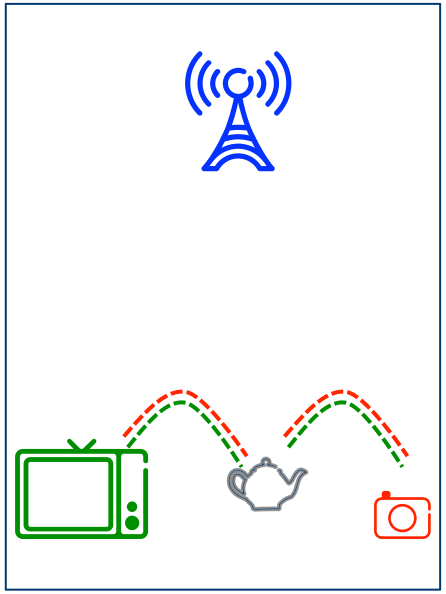
TDMA Cellular
- Single-cell
- 2 devices



NA-D2D
- Transit from TDMA cellular to D2D
- System timeslots savings



Distributed power control
- D2D pair self-manage power control
- Exploit closer proximity

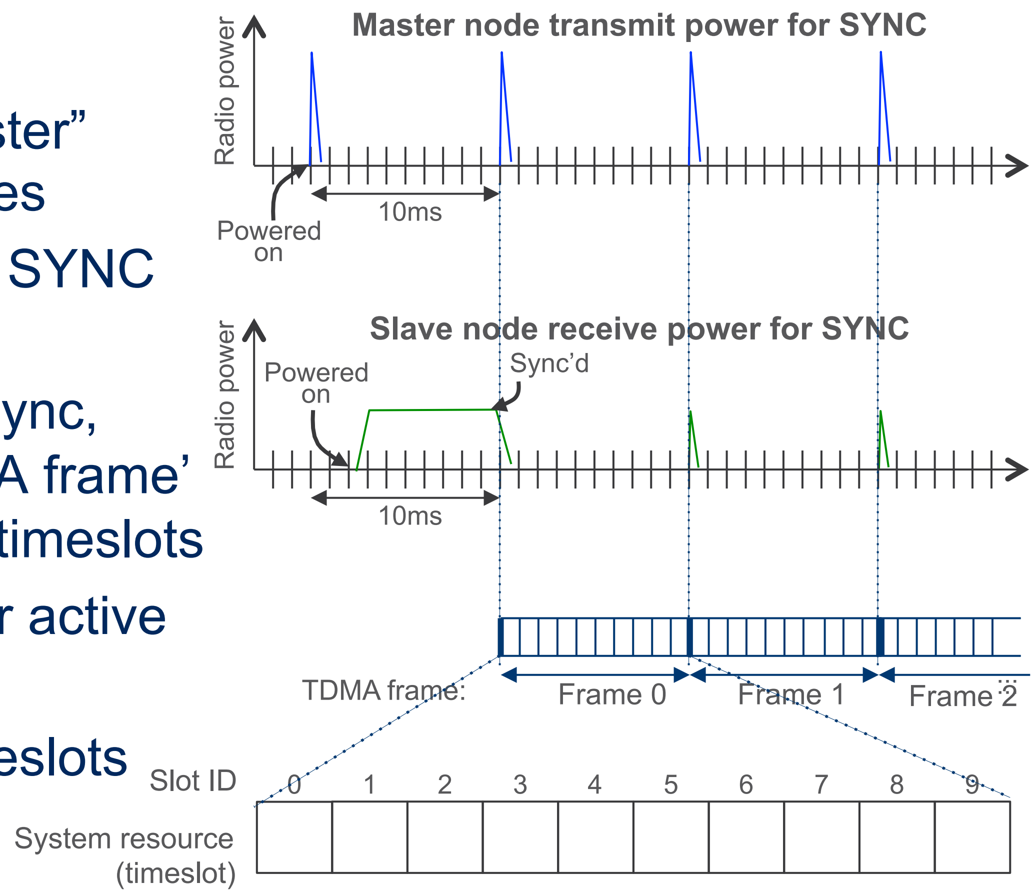


Intermediate relay
- “other” node helps out D2D pair
- Further system-wide power-savings

2010 → 2011 → 2012 → 2013

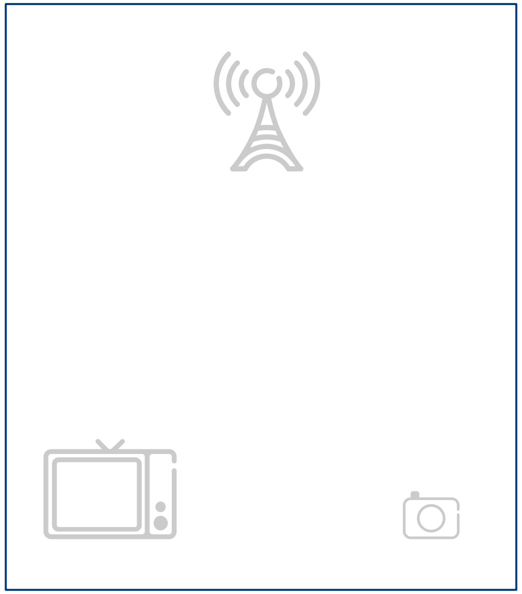
2010: TDMA CELLULAR

- Introduction of an over-the-air synchronization "overlay"
- Setup consists of a single "Master" node, and multiple "Slave" nodes
- Master node generates unique SYNC beacon every 10ms
- Slaves listen for SYNC. Upon sync, both have a concept of a 'TDMA frame' ➔can subsequently determine timeslots
- Radios are only powered-on for active timeslots (otherwise idle)
- Software used to configure timeslots



2010: TDMA CELLULAR

- We emulate a single-cell TDMA cellular mobile system
- Three nodes: a BLUE network-node (BS), a GREEN device (TV), and a RED device (camera)
- The Sequence is as follows…



Slot ID	0	1	2	3	4	5	6	7	8	9
System resource (timeslot)										

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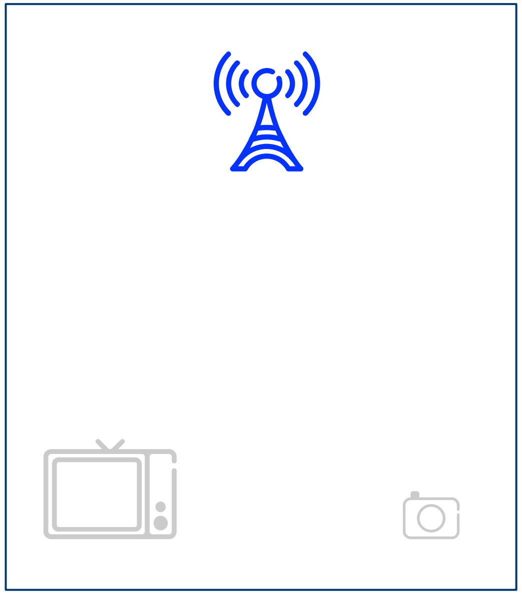
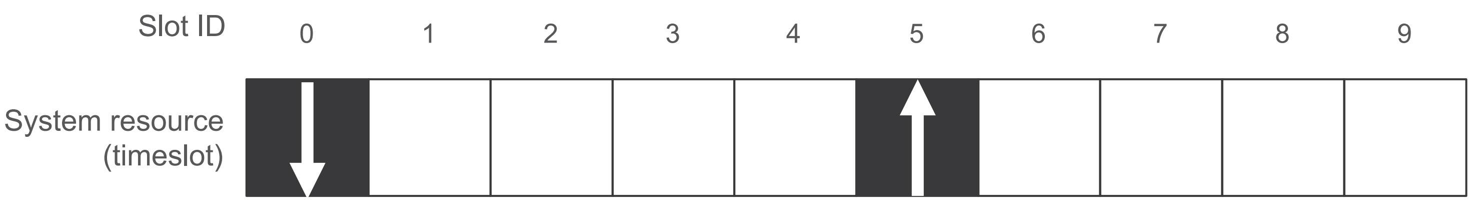


① The BLUE BS is 1st powered on
② periodic SYNC transmitted every 10ms
③ SLOT0 and SLOT5 allocated for DL and UL control (DLC & ULC)



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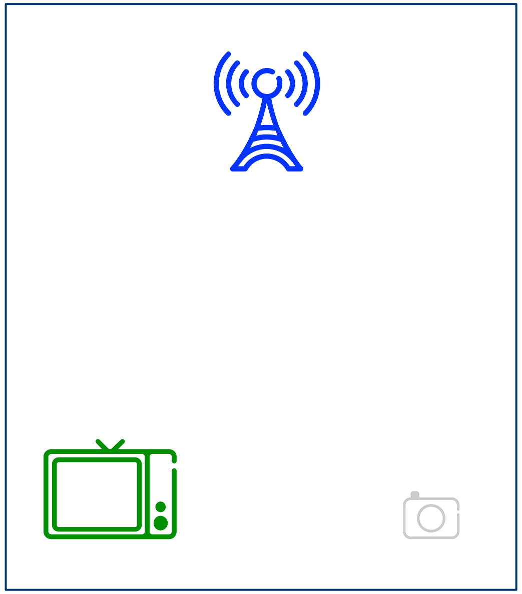
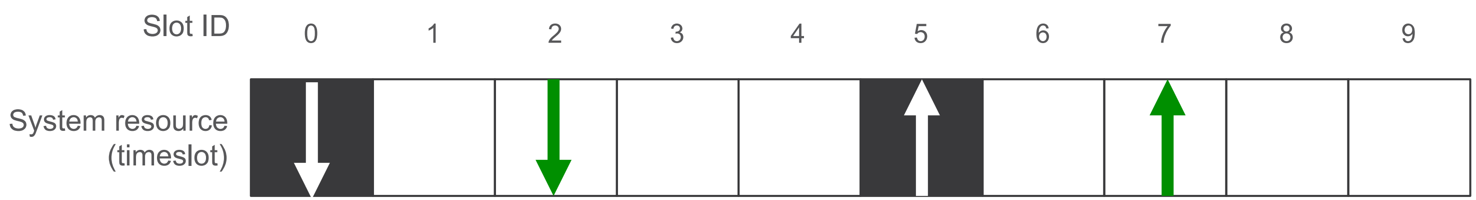


① The GREEN TV is powered on
② Detects SYNC; understands framing
③ Sends ATTACH-REQ to BS on the ULC
④ BS authenticates TV, then assigns UL&DL data slots via the DLC



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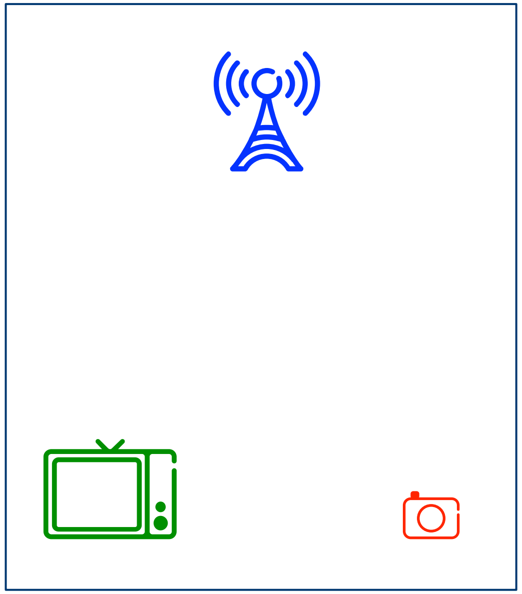
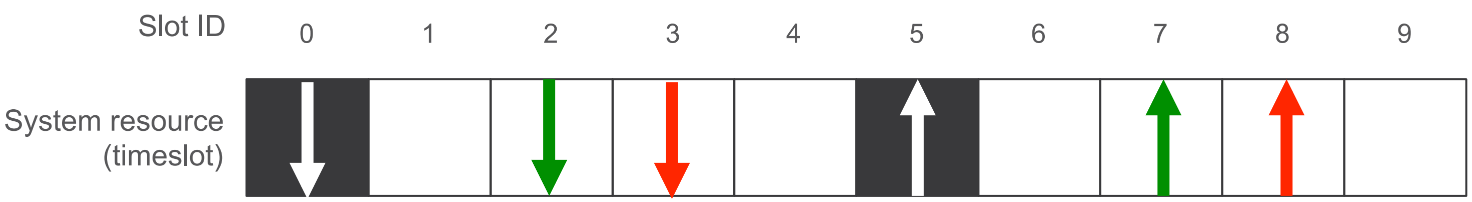


① Similarly, the RED Camera is powered on
② Detects SYNC; understands framing
③ Sends ATTACH-REQ to BS on the ULC
④ BS authenticates Camera and assigns UL&DL data slots via DLC



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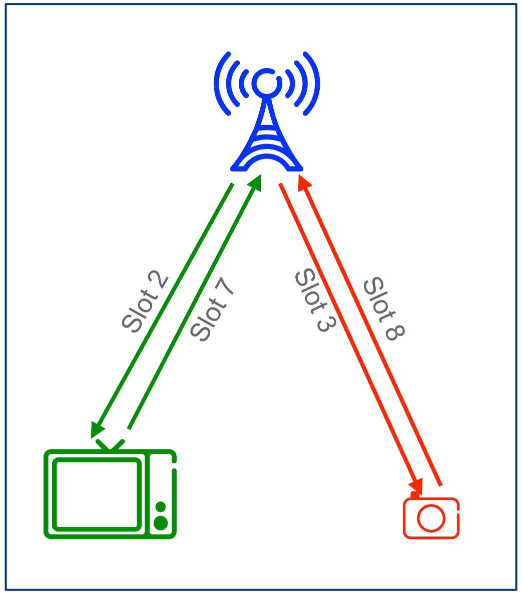
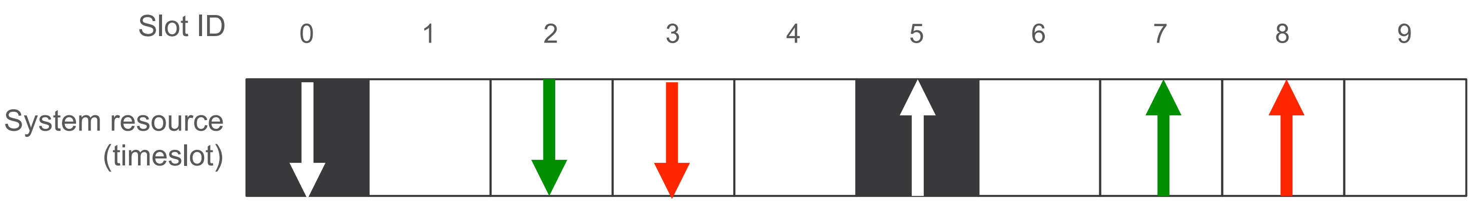


① User data generated by GREEN arrives at BS
② From packet-headers, BS forwards data onward to RED
③ Similarly for data in the RED ➔ GREEN direction



2011: NA D2D

› How to determine direct GREEN→RED link?

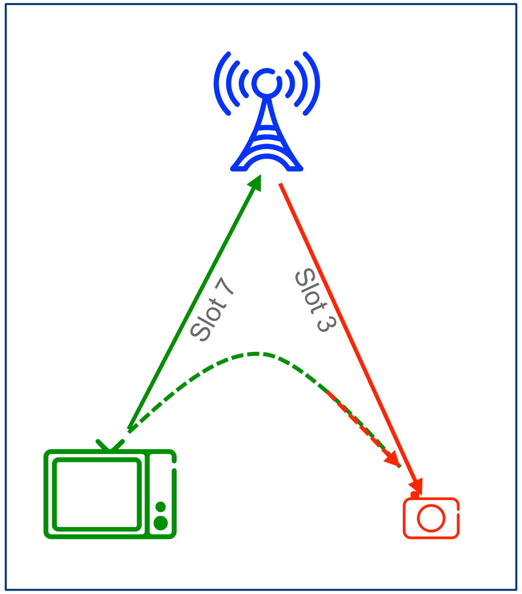
① RED receives data on DL slot (SLOT3)

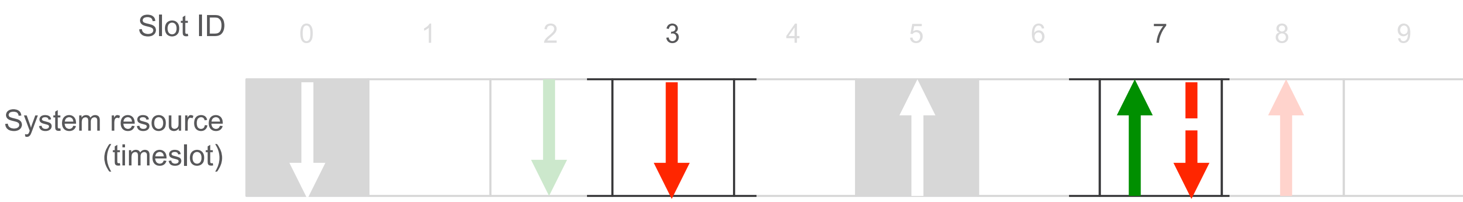
② Additionally, BS instructs RED via DLC, to also listen to SLOT7 (i.e., “eavesdrop” on GREEN’s UL transmissions)

③ RED should buffer these packets overheard on SLOT7

④ Simultaneously, BS also buffers packets received on SLOT7

⑤ At some point in the future, buffered packets from RED are sent to the BS for the network to evaluate





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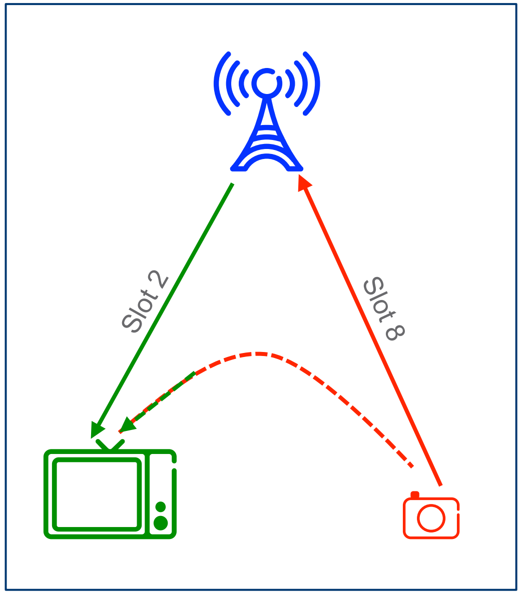
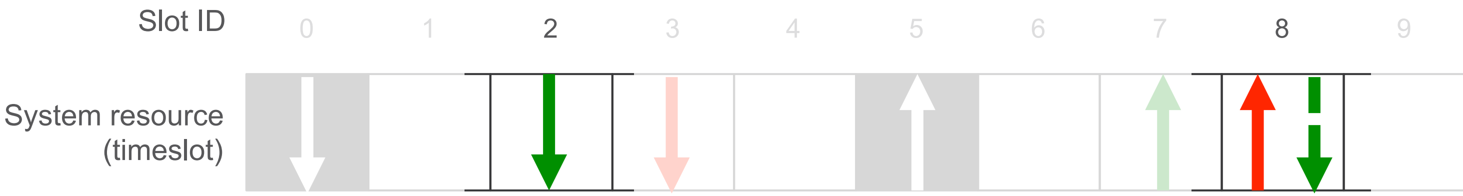
› Similarly, repeat for the RED→GREEN link





2011: NA D2D

- For the direct GREEN➔RED link, the network compares its own (i.e., BS) measurement, with received RED's report

Wireless node BLUE's console output

BS's own measurement

```
[745.006] D2D slot 7 direct-mode measurements:
[745.006]  =>Rx SN:  80  81  82  83  84  85  86  87  88  89
[745.006]  =>RSSI : 179 189 181 176 185 184 181 182 190 180
```

RED's measurement received @BS

```
[745.006] D2D_CTRLMSG_RPT_MEAS received from Node 9 @ FID=24
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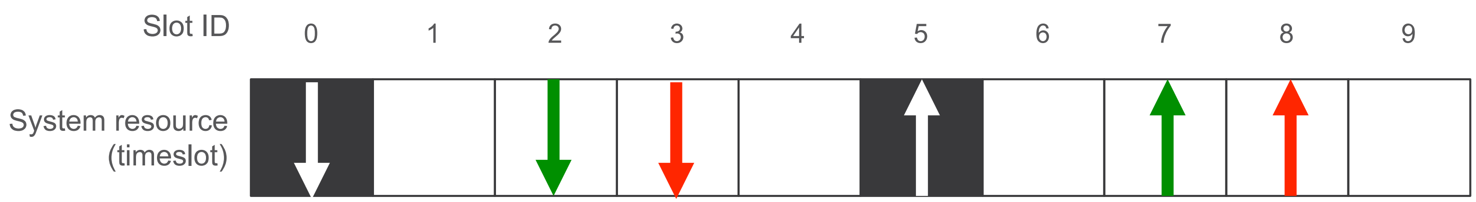
- Identical SNs in both measurement, and stronger RSSI in RED's report – direct GREEN➔RED link GOOD!



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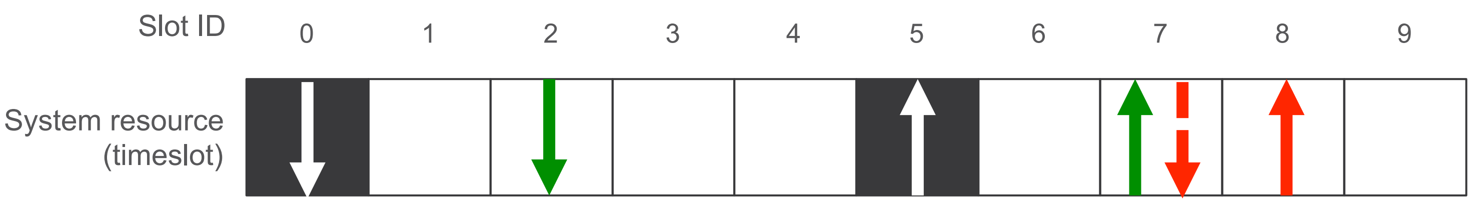

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```
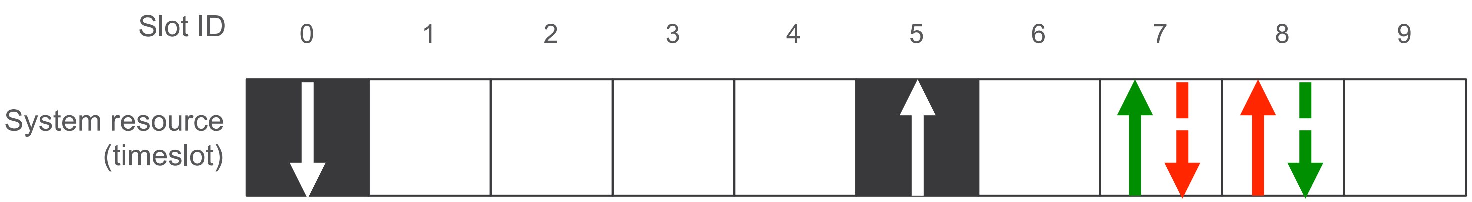

- Identical SNs in both measurement, and stronger RSSI in RED's report – direct GREEN→RED link GOOD!
- Reassign slots, notify device RED via DLC – SLOT3 now FREE!
- Similarly for the RED→GREEN direction – SLOT2 now FREE!



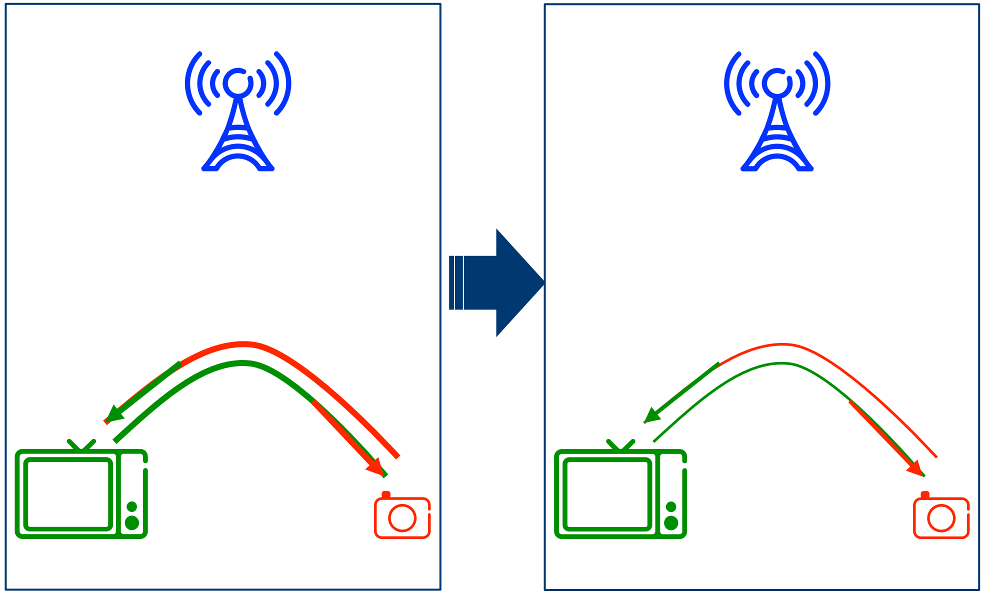
2012: POWER CONTROL

Concept

› Inter-device distance “closer”
  - should require less transmit-power

Challenge

› Network-independent device-managed power-control mechanism



› Implemented: MAC-based power-control
  1. Incorporated power-control into our simple radio MAC headers
  2. Receiver always ACKs received packet
  3. Transmitter up/down power - based on ACK/no-ACK
  4. MAC header contains $RSSI_{delta}$ of last received packet: other-end always knows how “loudly” transmitted packet was received

2013: D2D REPEATERS

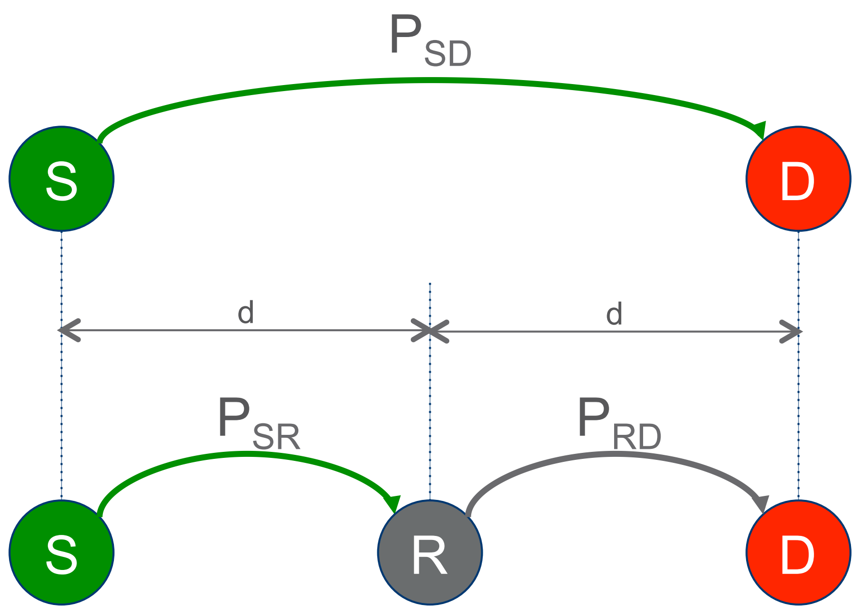
Concept

- Thriftier to take “smaller hops”

$$(P_{SR} + P_{RD}) \ll P_{SD}$$

- Positive:
  system-wide power utilization will reduce

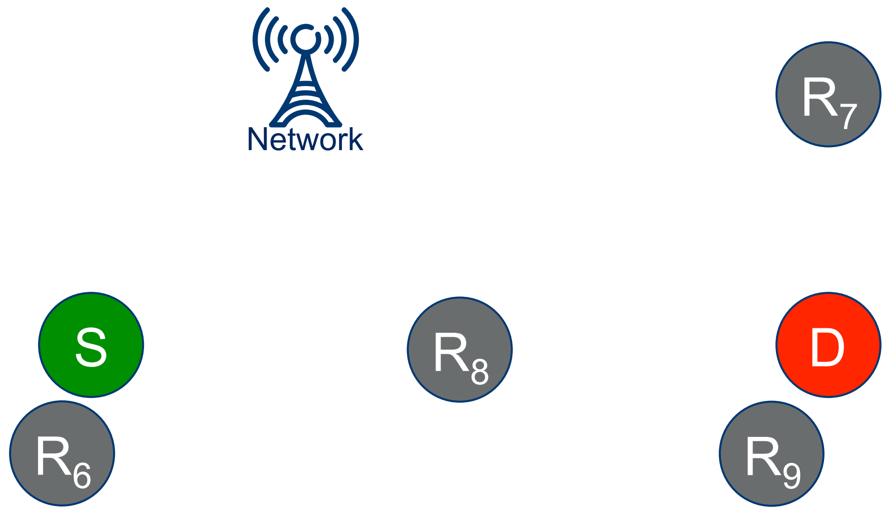
- Negative:
  additional delays, i.e., 2 transmissions from S to D, instead of 1.



2013: D2D REPEATERS

Challenge I

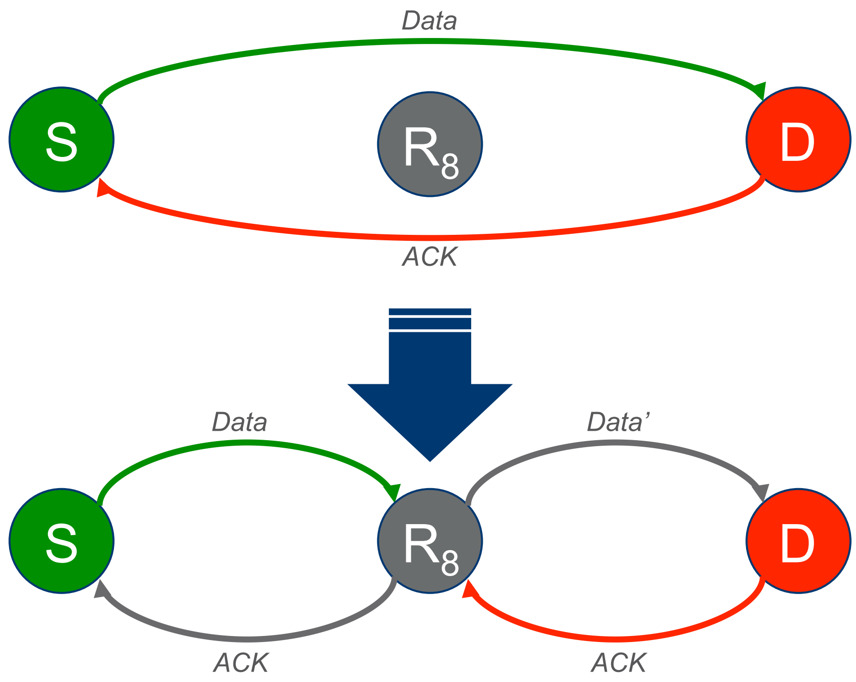
› How do determine the best R to repeat?



2013: D2D REPEATERS

Challenge II

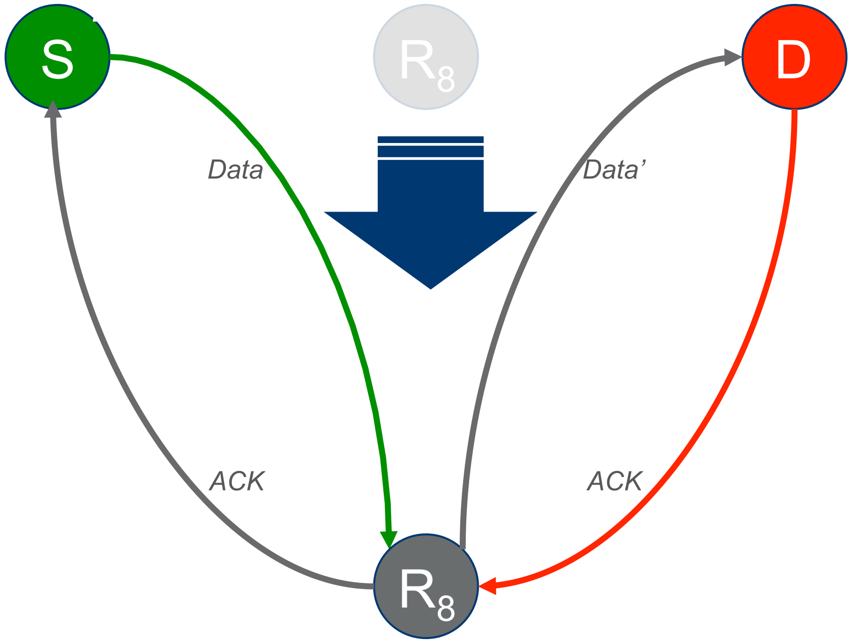
› How to change topology?



2013: D2D REPEATERS

Challenge III

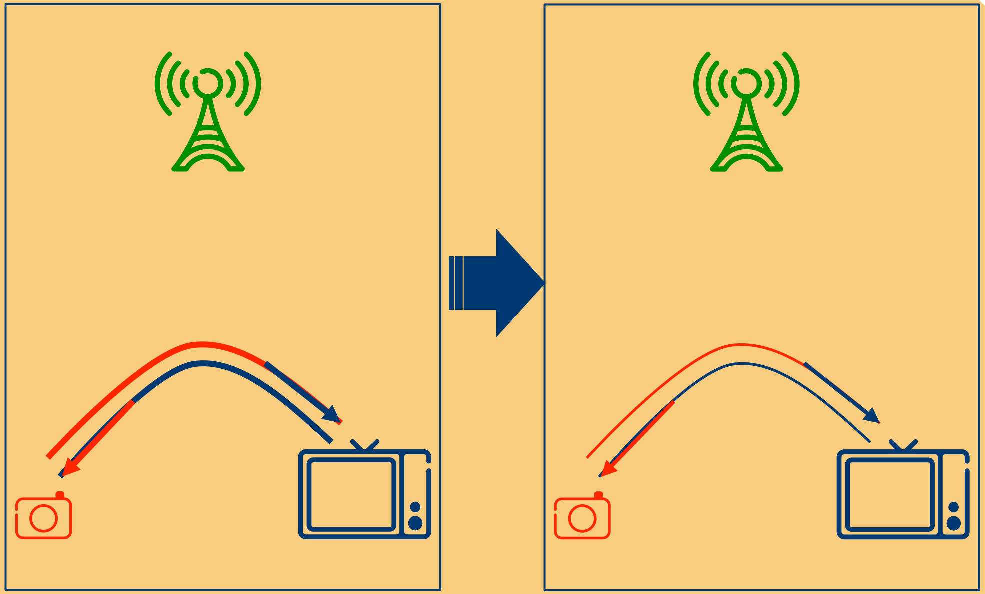
- Mobility and topology changes



DEMONSTRATION TODAY

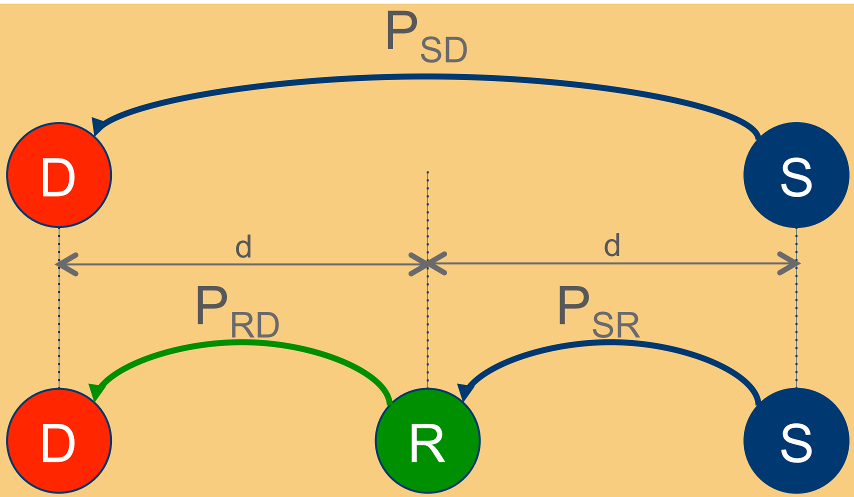
D2D power control

- MAC-based
- Between direct-communicating device-pairs



D2D repeaters

- Device-based repeater for multi-hop direct-communicating device pairs



CONCLUSION

"To study and investigate new wireless communications mechanisms via prototyping and proof-of-concept"

- Designed and prototyped various NA-D2D mechanisms
- Implementation behaved mostly as expected
- Discovered subtle real-world issues from implementation (timing, asymmetries)
- Fed discoveries back to design process – more robust mechanism

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