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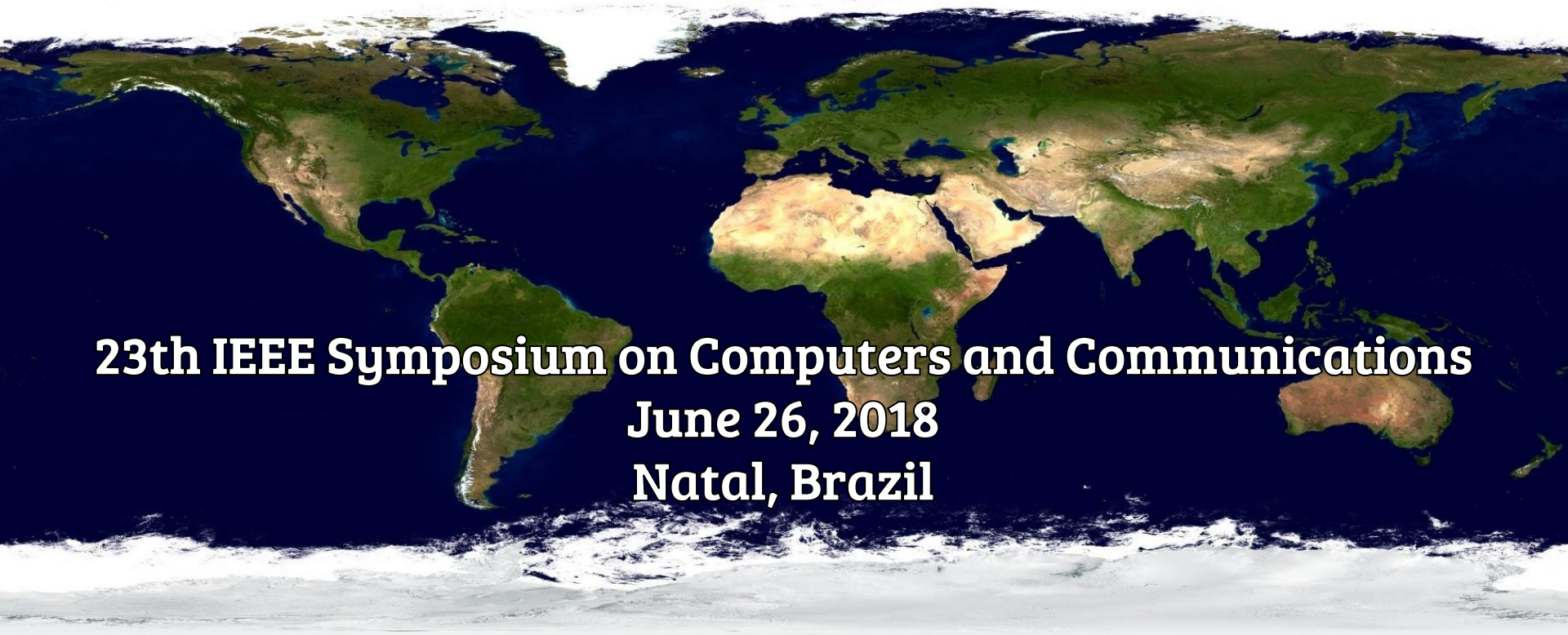
MSHCS-MAC: A MAC Protocol for Multihop Cognitive Radio Networks based on Slow Hopping and Cooperative Sensing approach



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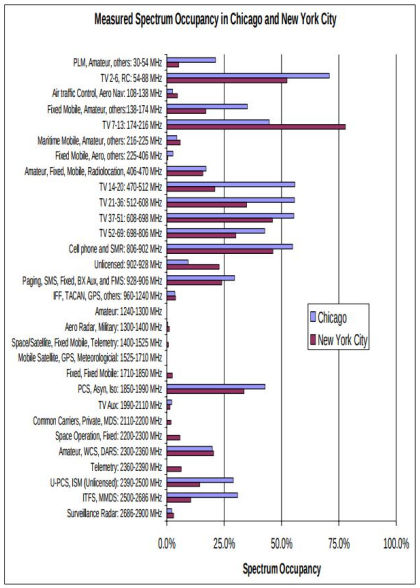
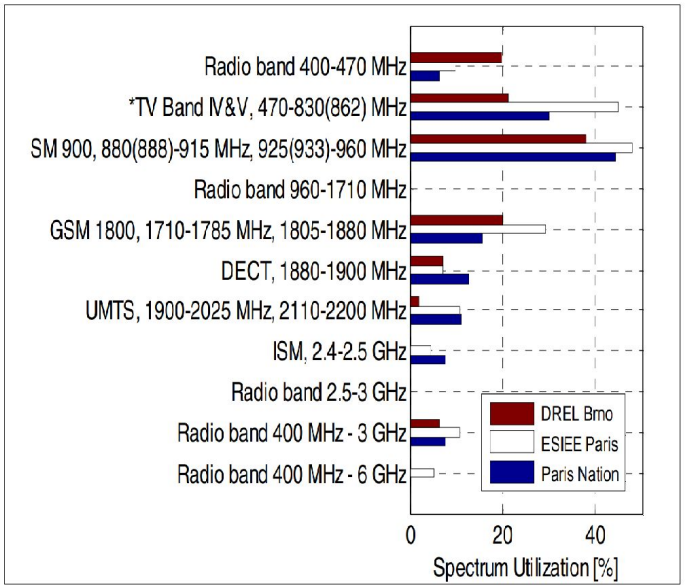
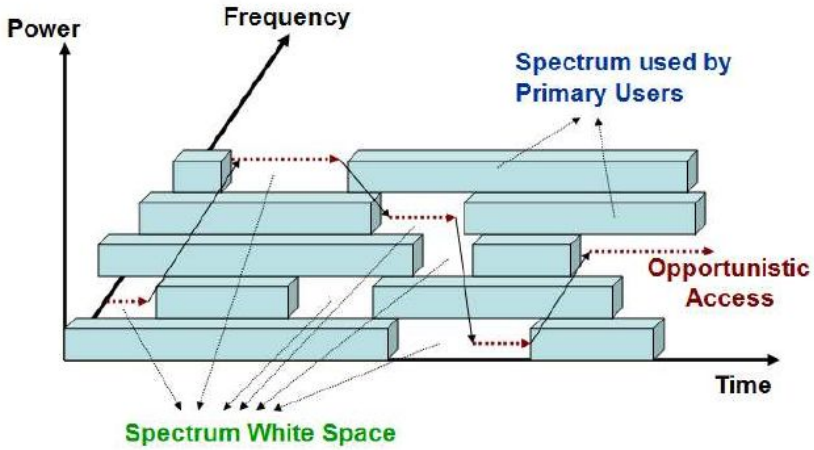
1. Introduction - Motivation for CR Networks



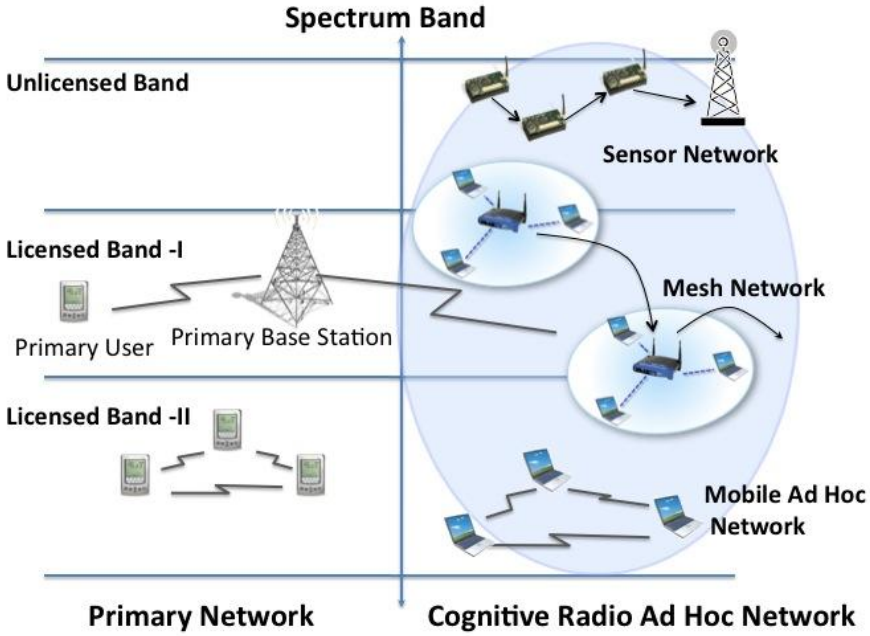




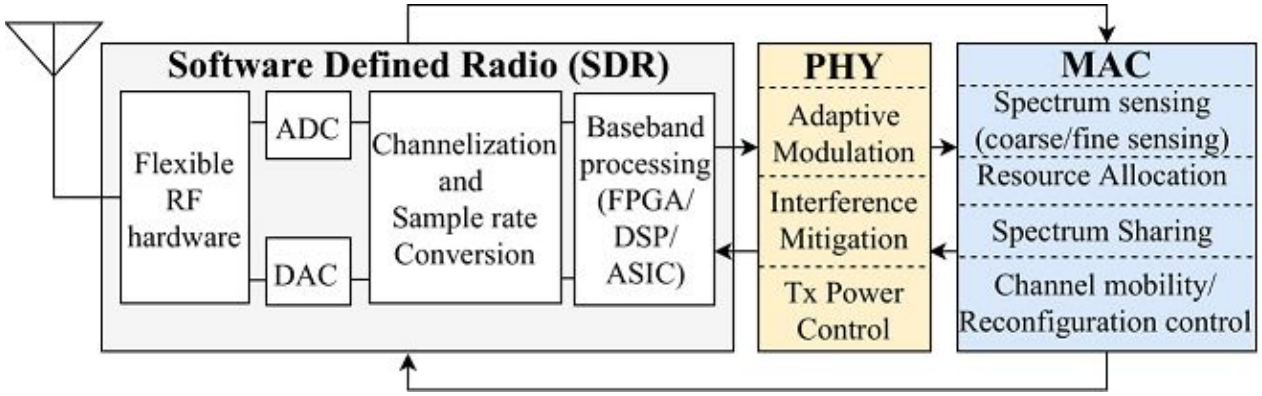
- Growing demand for wireless spectrum.
- Spectrum utilization of many channels (TV, satellite, military, etc.) is low.
- Allocate more spectrum ?
- => Cognitive Radio network [*].

** Mitola, J. & Maguire, G. Q., "Cognitive radio: making software radios more personal", IEEE personal communications, 1999*

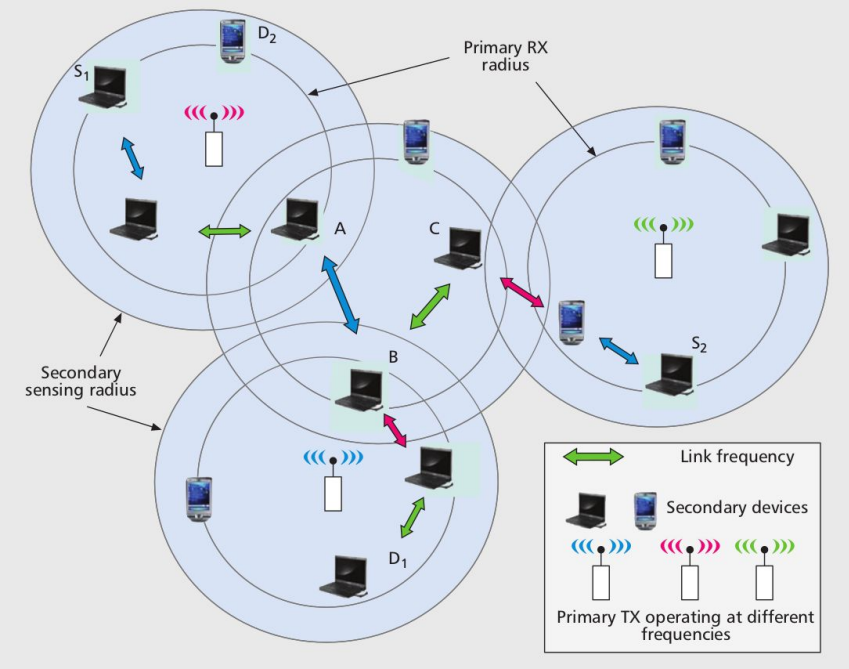
1. Introduction - CR MAC protocols.



- **Spectrum sensing:** detect white spaces and Primary User's (PU) activities.
- **Channel mobility:** communicate over multiple channels and evacuate as soon as PUs arrive.
- **Resource allocation:** opportunistically assign available channels to CR devices.
- **Spectrum sharing:** prevent contentions and harmful interferences with PUs.



1. Introduction - Challenges of CR MAC protocols.



Similar to classic multi-channel network but different.

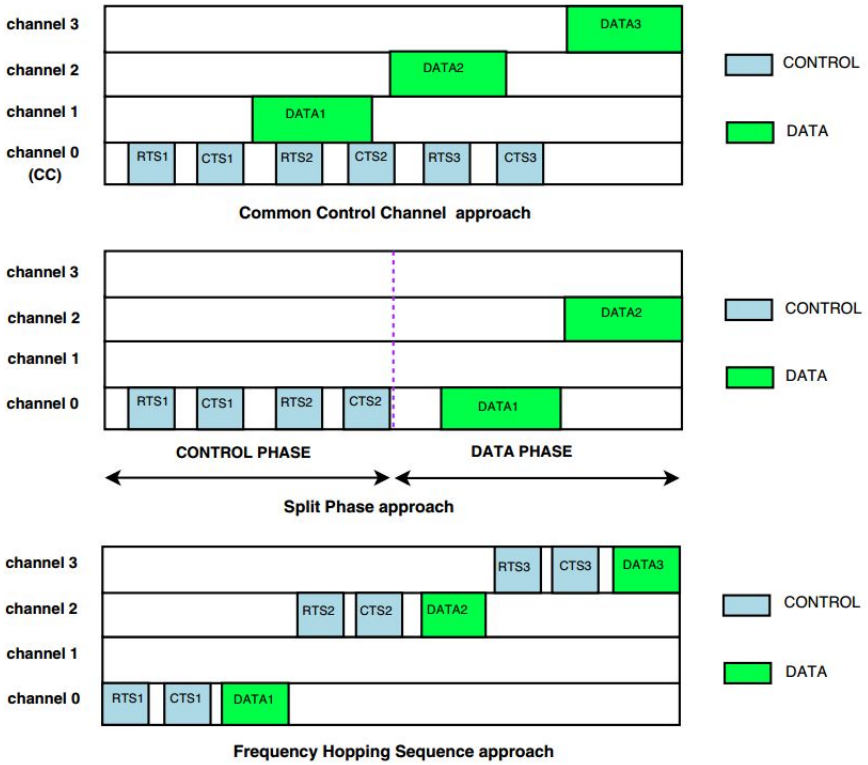
- Opportunistic nature.
  - Number of available channels is dynamic with time and space.
- Need sophisticated sensing method to detect white spaces and protect PUs.

Multi-hop CR MAC challenges:

- **Coordination challenges in neighbor discovery:** how to detect nearby relay nodes?
- **Heterogeneity in RF ranges:** different freqs. => different transmission ranges?
- **Deafness problem:** sender-receiver are not always in the same channel?
- **Distributed Spectrum Access at Relay Nodes:** utilize the use of multi-channel.

** Sengupta, S. & S., KP, "Open research issues in multi-hop cognitive radio networks", IEEE Communications Magazine, 2013*

2. Related Works



Three categories of state-of-the-art CR MAC protocols:

- **Common control channel (CCC) (out-of band):**
  - Dedicated control channel.
  - Synchronization is not strict.
  - A dedicated radio (i.e transceiver) always stay in CCC.
  - Prone to jamming and CCC saturation.
- **Split-phases (out-of band):**
  - Use of 1 radio is possible.
  - Time sync. is needed.
  - Wasting free data channels during control phase.
- **Frequency hopping (in-band):**
  - More reliable, 1 radio is possible.
  - Strict time sync. is required.

2. Related Works (cont')

Three categories of CR MAC protocols:

- **Common control channel (CCC) (out-of-band):**
  - HC-MAC, OS-MAC, and KNOWS
- **Split-phases (out-of-band):**
  - C-MAC, MMAC-CR
- **Frequency hopping (in-band):**
  - SYN-MAC (2 radios), DH-MAC (1 radio), **SHCS-MAC[*] (1 radio, our previous work)**.

SHCS-MAC :

- **Pros:**
  - Only use one radio (i.e. transceiver), first one to include cooperative sensing in frequency hopping approach.
  - Better aggregate throughput and coexistence with other CRNs and PUs.
- **Cons:**
  - Limited within 1 hop.
  - Evaluated in simulation which doesn't reflect practical networks.

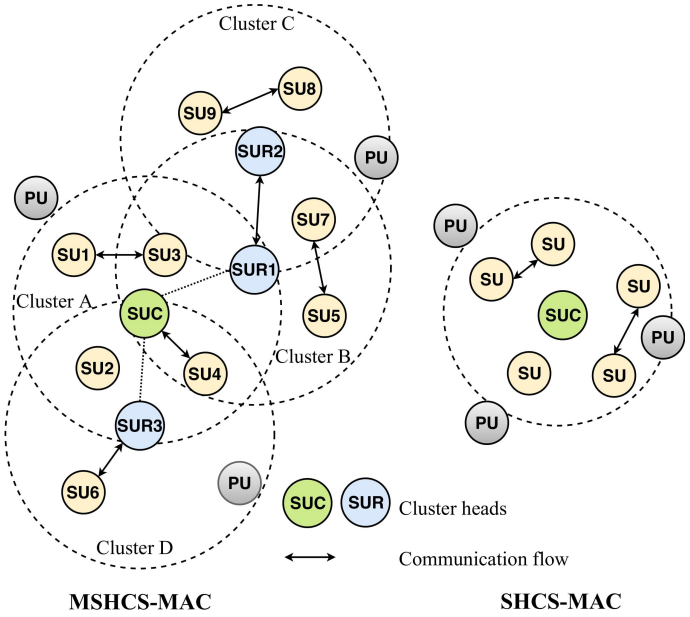
** Lee, Y. & Kim, D., "Slow hopping based cooperative sensing MAC protocol for CRNs", Computer networks, Elsevier, 2014.*

2. Related Works - Contributions

Contributions of MSHCS-MAC

- Support of multi-hop communication without dedicated control channel and multiple transceivers.
- Integration of essential CR-MAC features such as bootstrapping, multi-channel operation, cooperative spectrum sensing and time synchronization.
- Practical implementation and evaluation on commercial devices (GNU Radio, USRPs, Linux PC, Android devices.)

3. MSHCS-MAC - System Model



System Architecture: Coordinator-based CR network (CB-CRN) and cluster tree topology

- Primary User (PU), Secondary User Coordinator (SUC), Secondary User Relay Node (added in MSHCS-MAC, SUR), Secondary User (SU).
- Active beaconing
  - Available channel notification
  - Channel hopping scheduling, time synchronization.

Frequency hopping scheme:

- Time is divided into time slots (Ts): sensing, beacon, reporting, and data durations.
- All devices in a cluster will move to a random channel at the end of each Ts => common hopping sequence (CHS).

Assumption:

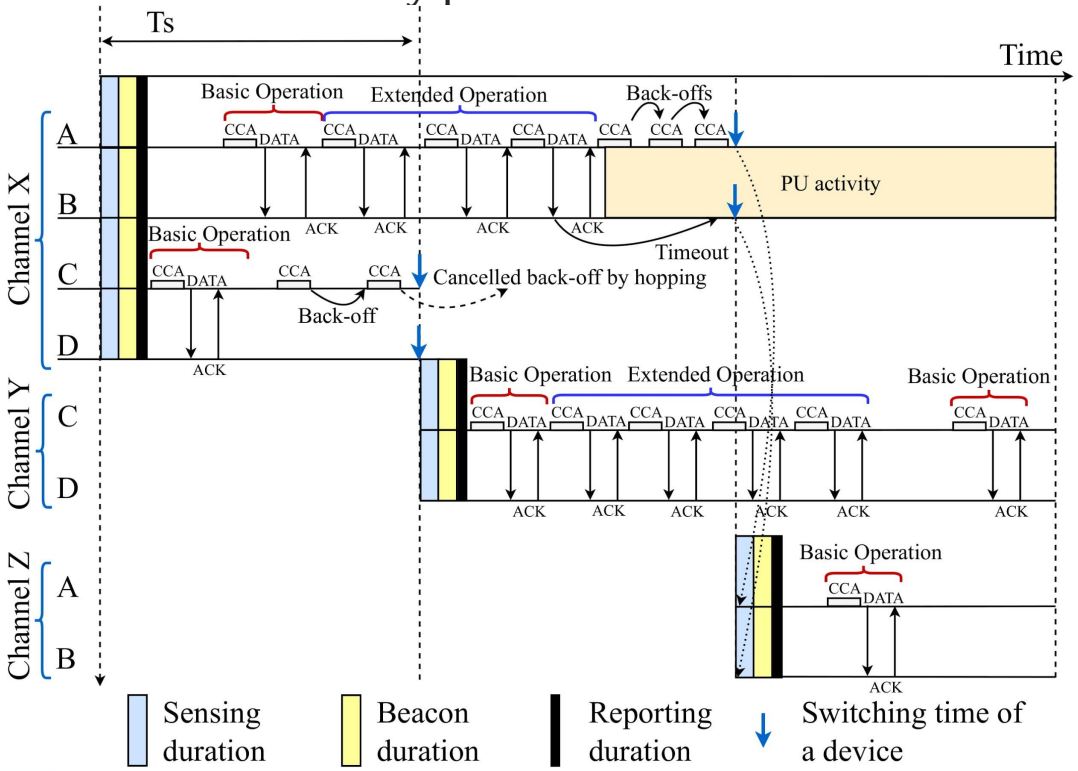
- Only cluster heads (SUC and SURs) have routing ability.

3. MSHCS-MAC - Multi-channel operation

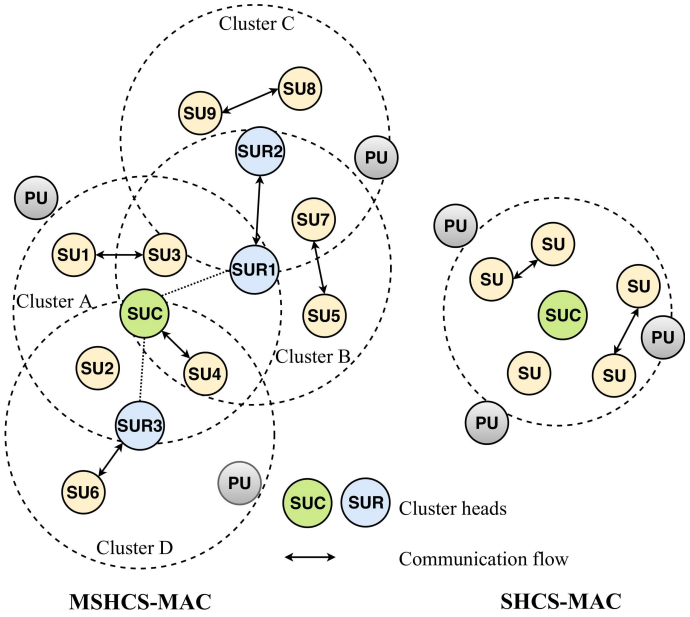
Basic operation: contention-based CSMA/CA protocol is used.

Extended operation:

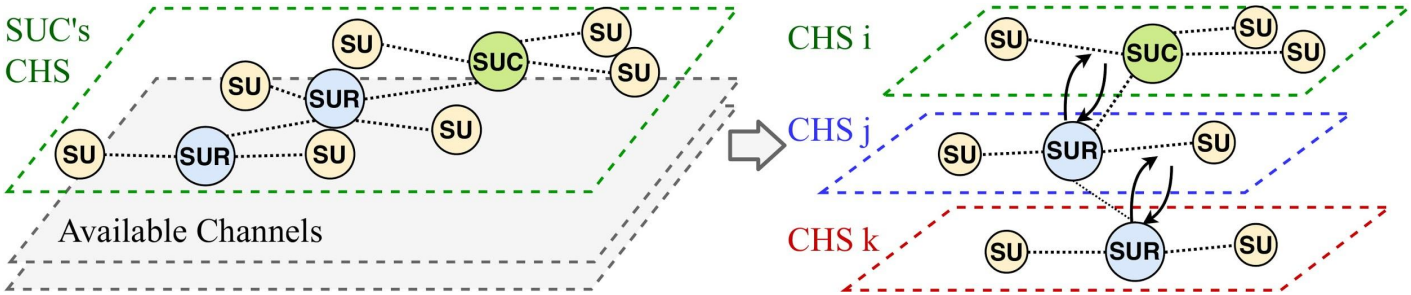
- Performed when there are more data between sender and receiver.
- Return to common hopping sequence:
  - Sender: no more data or CSMA/CA failed to transmit.
  - Receiver: didn't receive any packet after timeout.



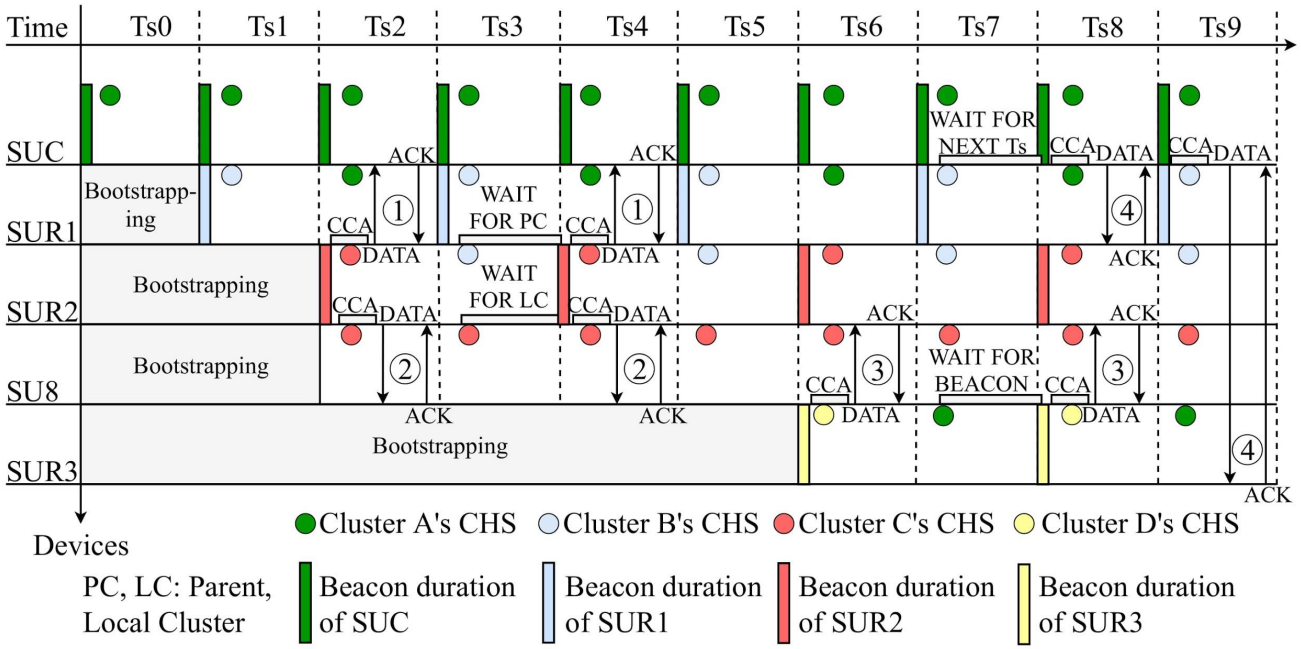
3. MSHCS-MAC - Secondary User Relay (SUR) node



- **Secondary User Relay node is added in MSHCS-MAC.**
- **Following the same CHS is inefficient in multihop environment:** accumulated time sync. error => false alarms; leave channels unused.
- **SUR has 2 independent hopping sequences:**
  - Parent cluster and local cluster.
  - Local cluster has its own beacon.
  - Only 1 radio => Scheduling is needed to keep connection between both clusters.
- Better utilize the spectrum but **deafness** problem?



3. MSHCS-MAC - Inter-cluster communications



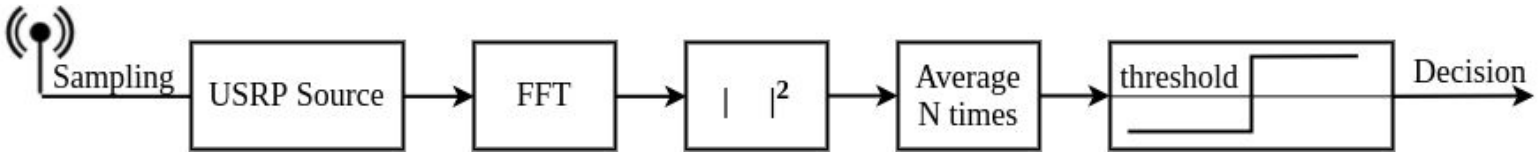
SUR doesn't always stays in 1 CHS => **Deafness problem** for inter-cluster communication.

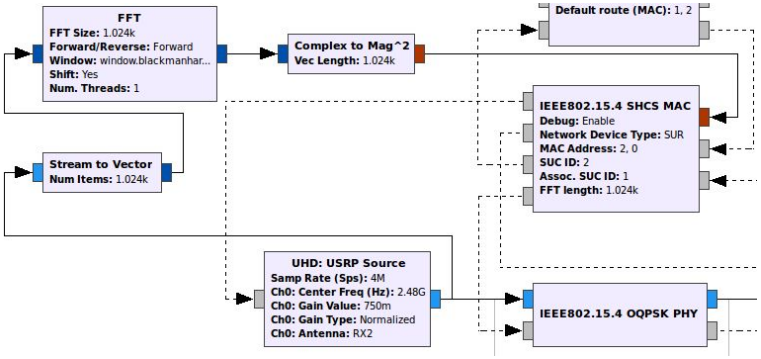
Four cases of inter-cluster communications:

1. SUR -> parent cluster head: wait until SUR hops to parent cluster.
2. SUR -> SU in local cluster: wait until SUR returns to local cluster.
3. SUC -> SUR (in SUC's cluster): SUC needs to keep tracks channel hopping indexes of each SUR.
4. SU -> SUR (SU's cluster head): wait for beacon from SUR.

3. MSHCS-MAC - Cooperative Spectrum Sensing

Local Sensing (Sensing): Energy detection technique.

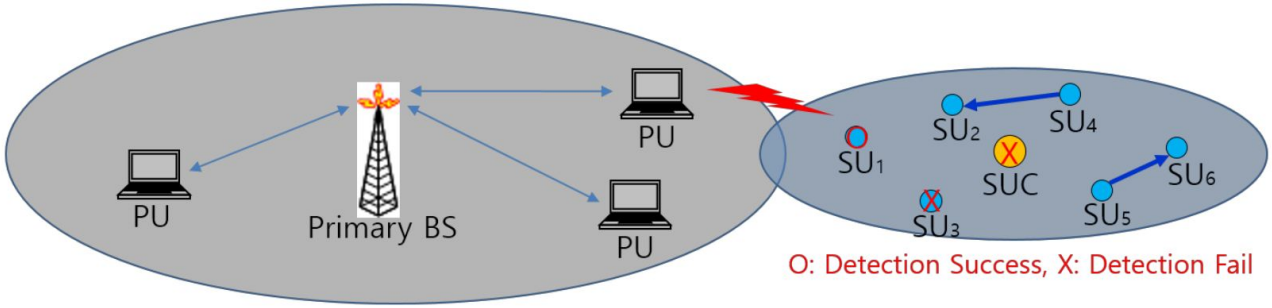




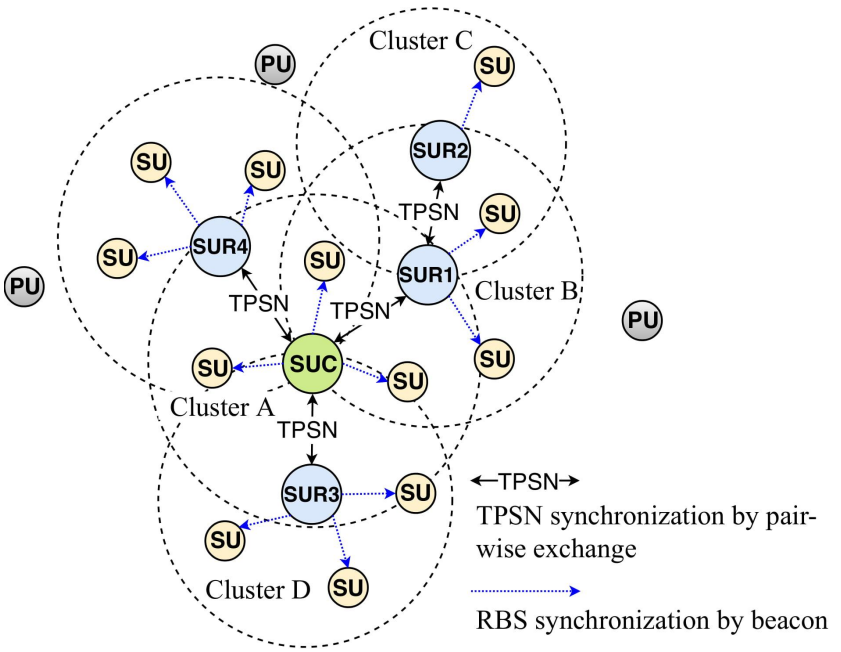
$$P = \frac{1}{n} * \sum_{i=0}^{n-1} |x[i]|^2;$$

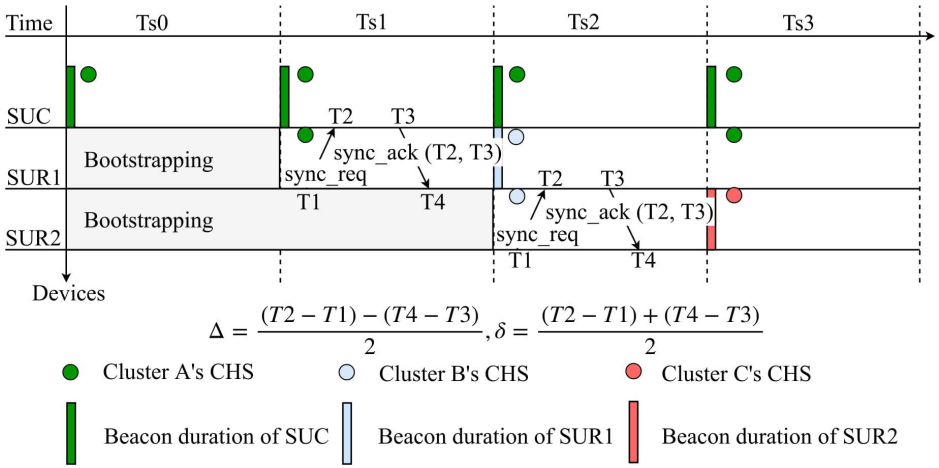
x[i]: discrete samples of the signal at regular intervals, with n points stretching from 0 to n-1.

Cooperative Sensing (Reporting): OR-Rule. Pilot signal is used in report duration to notify PU activity in reporting duration.



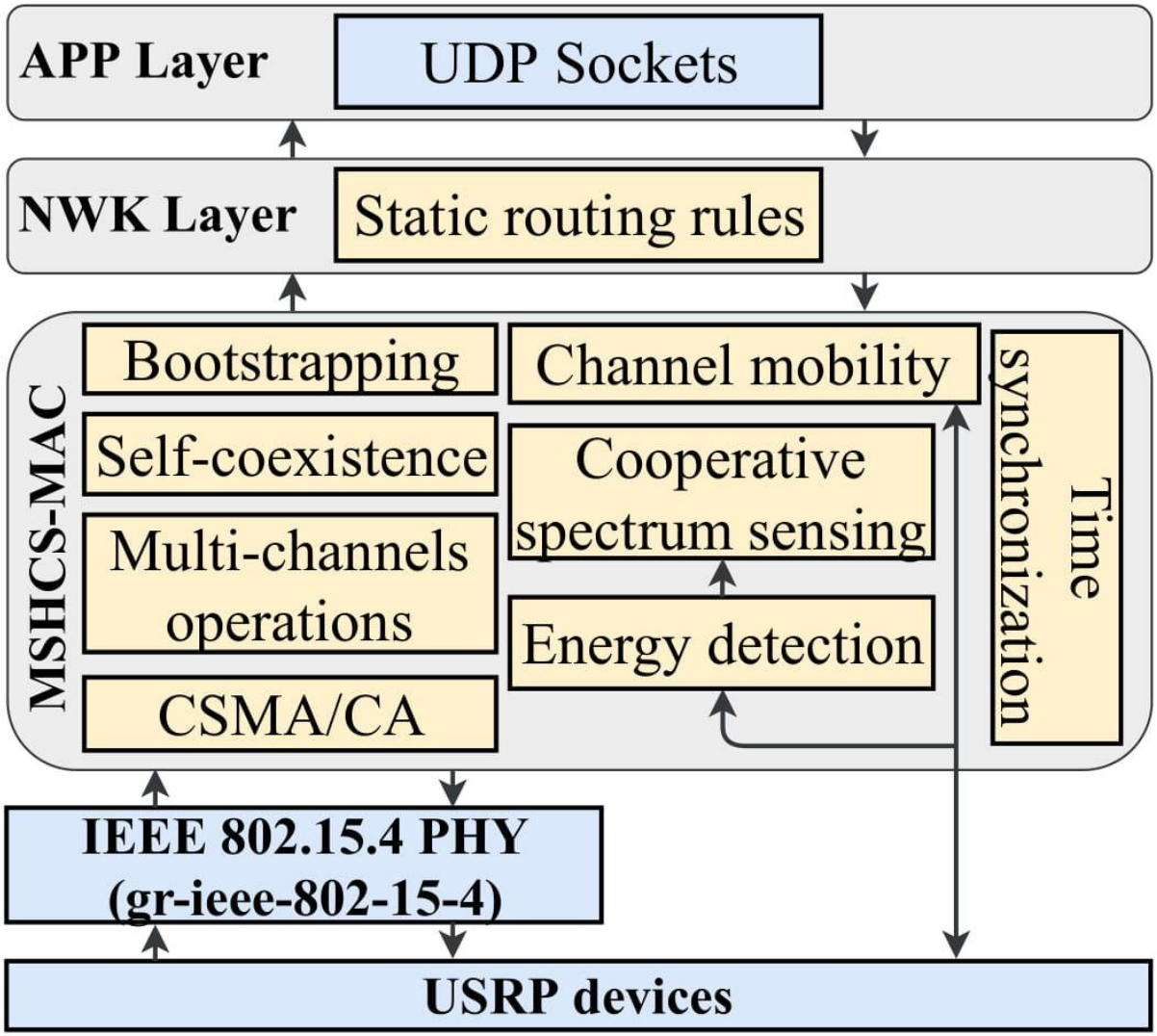
3. MSHCS-MAC - Time Synchronization



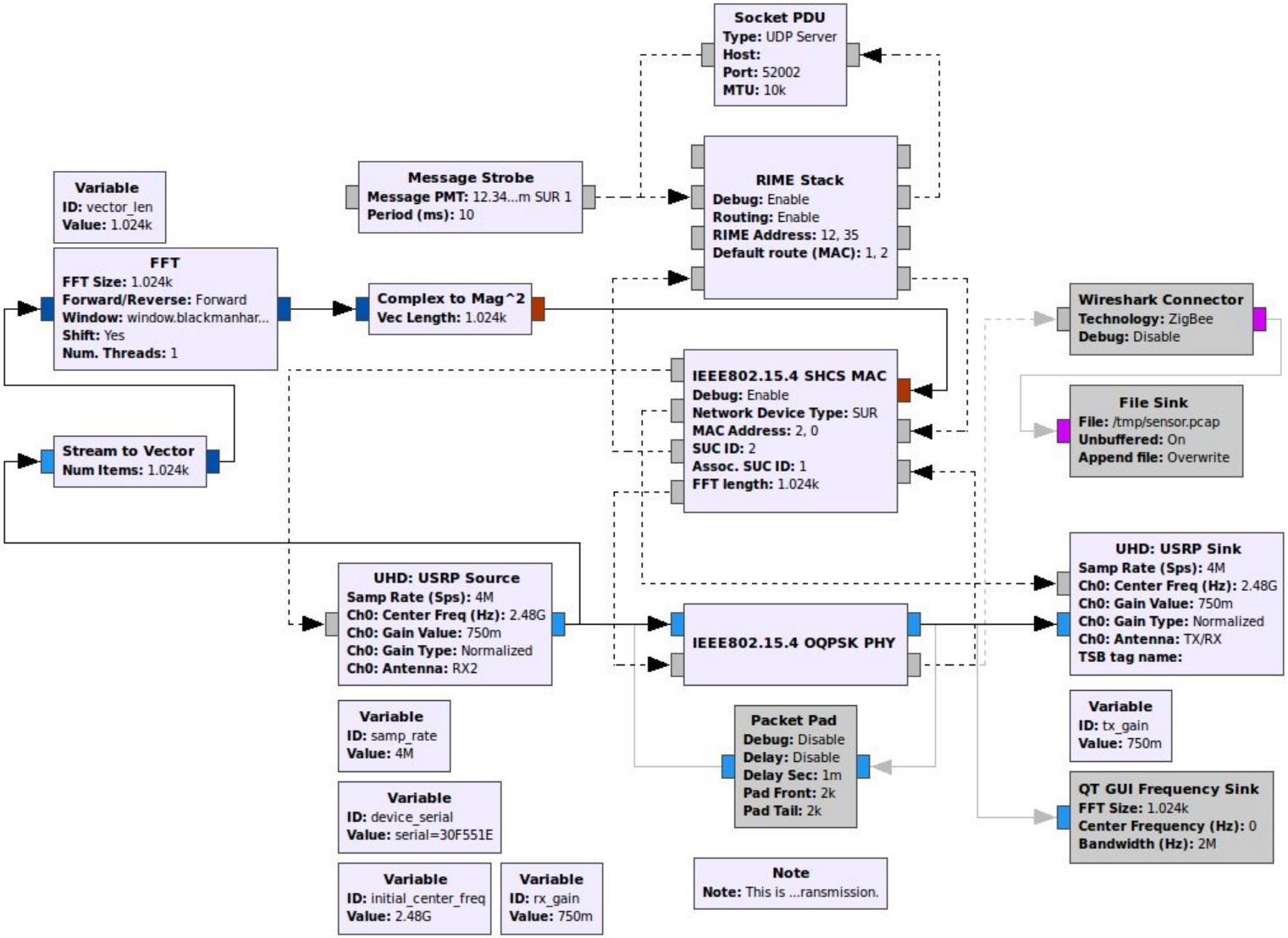


- Time synchronization is needed to keep all nodes synchronized.
- Unsynchronized nodes => false alarms, mistmaches in data transmission => reduce packet delivery ratio.
- Hybrid time sync. scheme is used:
  - **Reference Broadcast Synchronization (RBS)**: Coarse-grained (ms accuracy) cluster level.
  - **Timing-sync Protocol for Sensor Networks (TPSN):** Fine-grained protocol, accuracy in sub-ms level (~200us), Synchronize all clusters together.

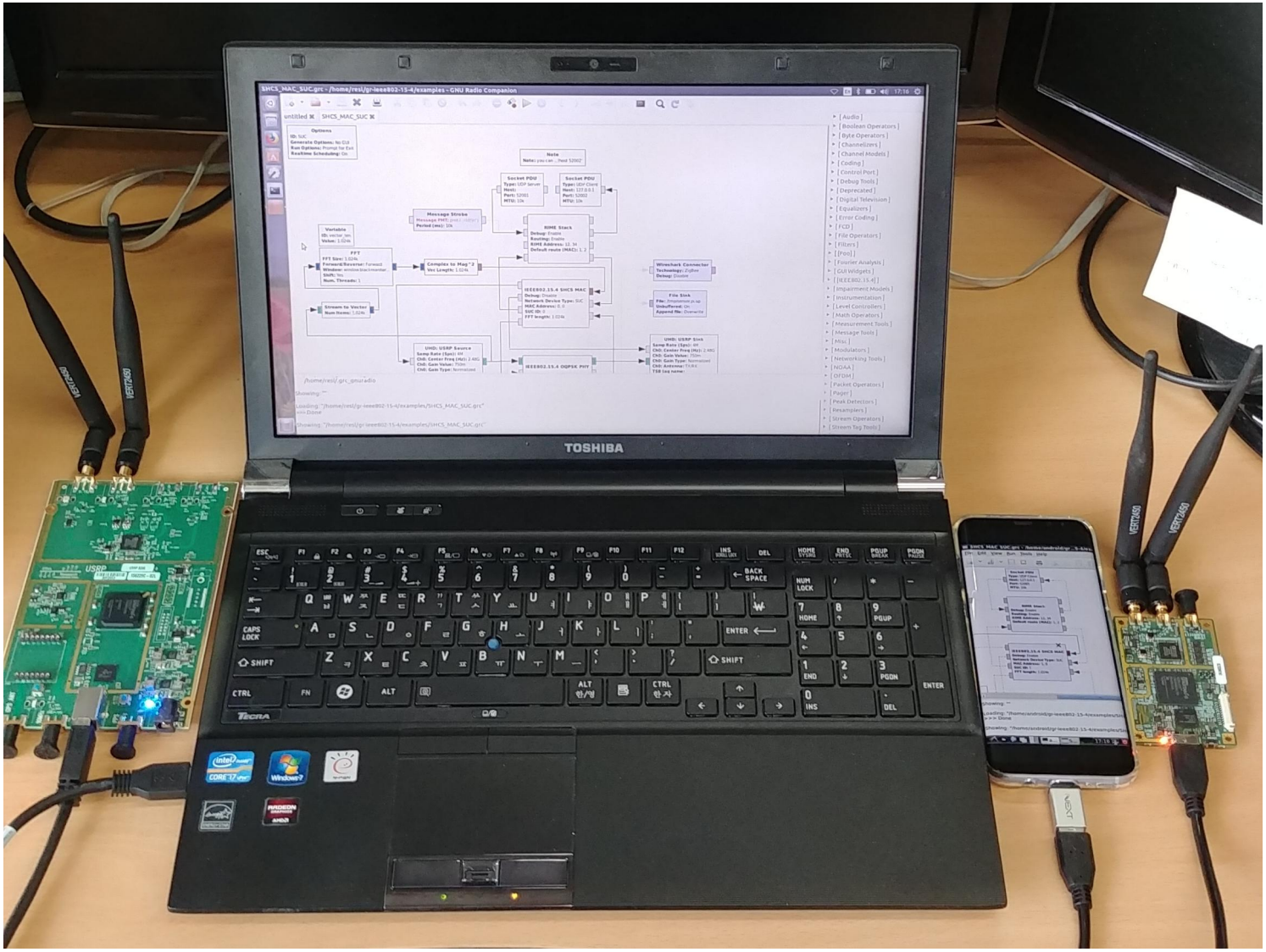
4. MSHCS-MAC implementation - Overall architecture



4. MSHCS-MAC implementation - In GNU Radio

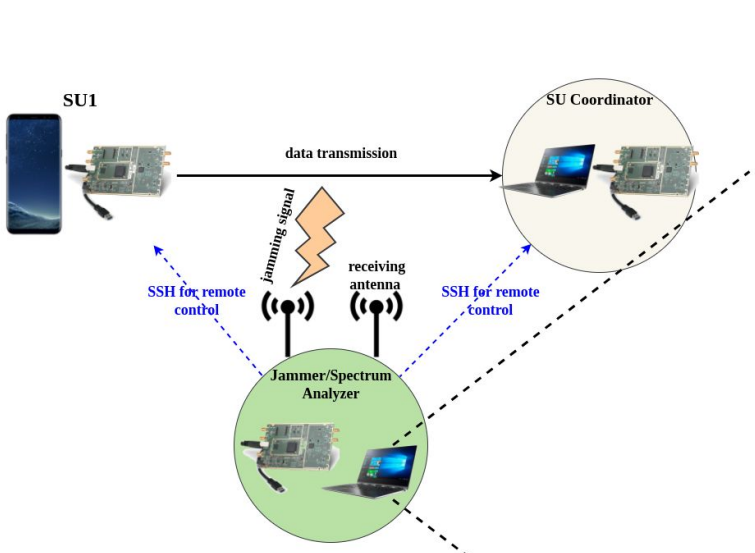


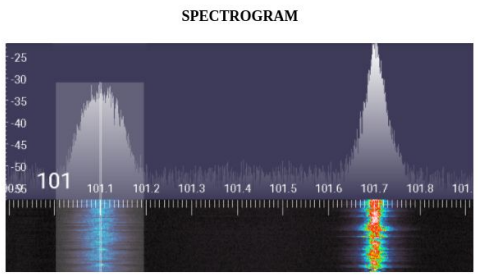
4. MSHCS-MAC implementation - Platforms

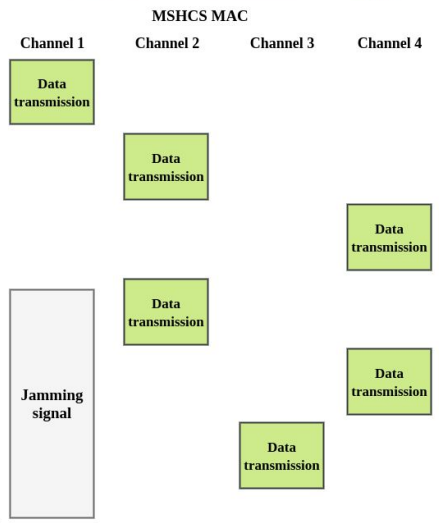


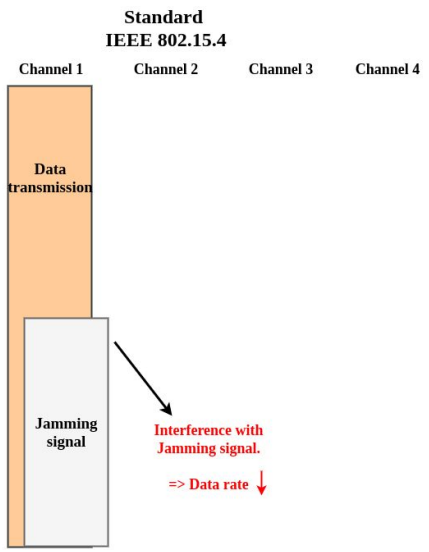
5. Demonstration and Evaluation - Performance under PU activity.

- SU1 transmits directly to SUC with a jammer (PU activity) and a spectrum analyzer in the middle.
- Compare performance of MSHCS-MAC and standard IEEE 802.15.4 MAC
- 4 channels (#23 - 26: 2.65 - 2.8 GHz) are used.
- Ts = 200ms, Tsensing = 10ms, Tbeacon = 5ms, Treporting = 5ms.

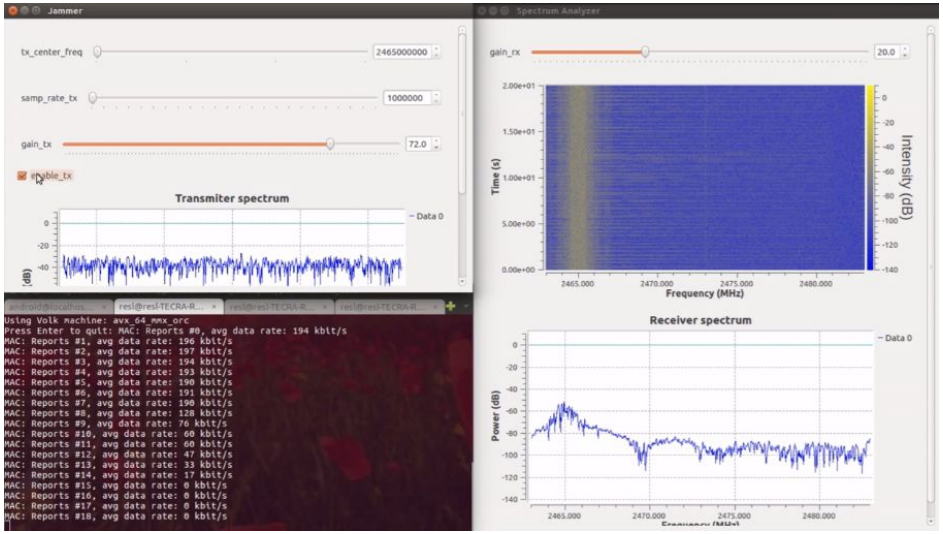


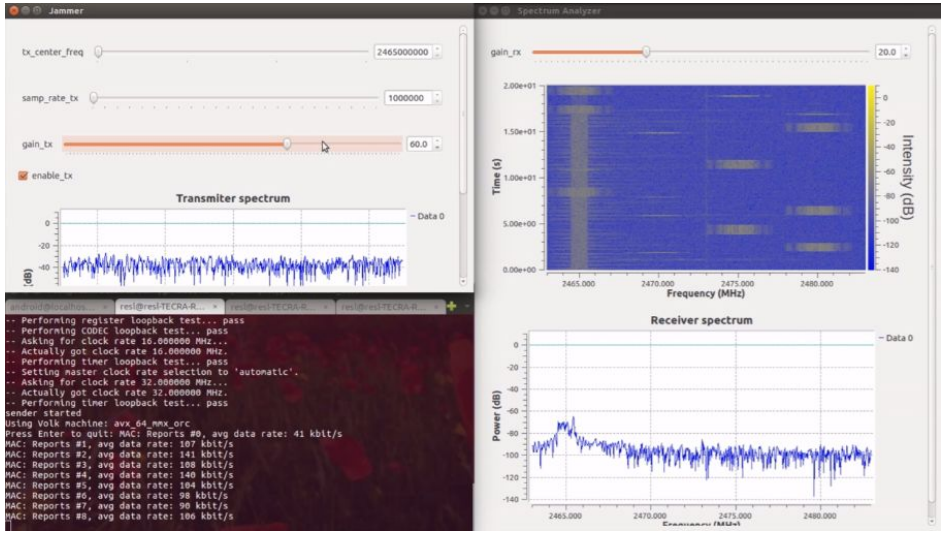


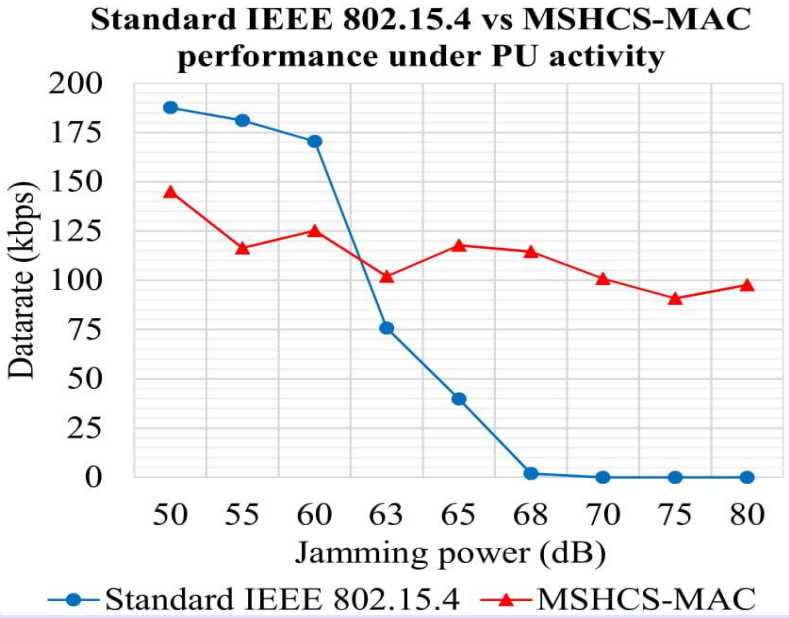




5. Demonstration and Evaluation - Performance under PU activity.



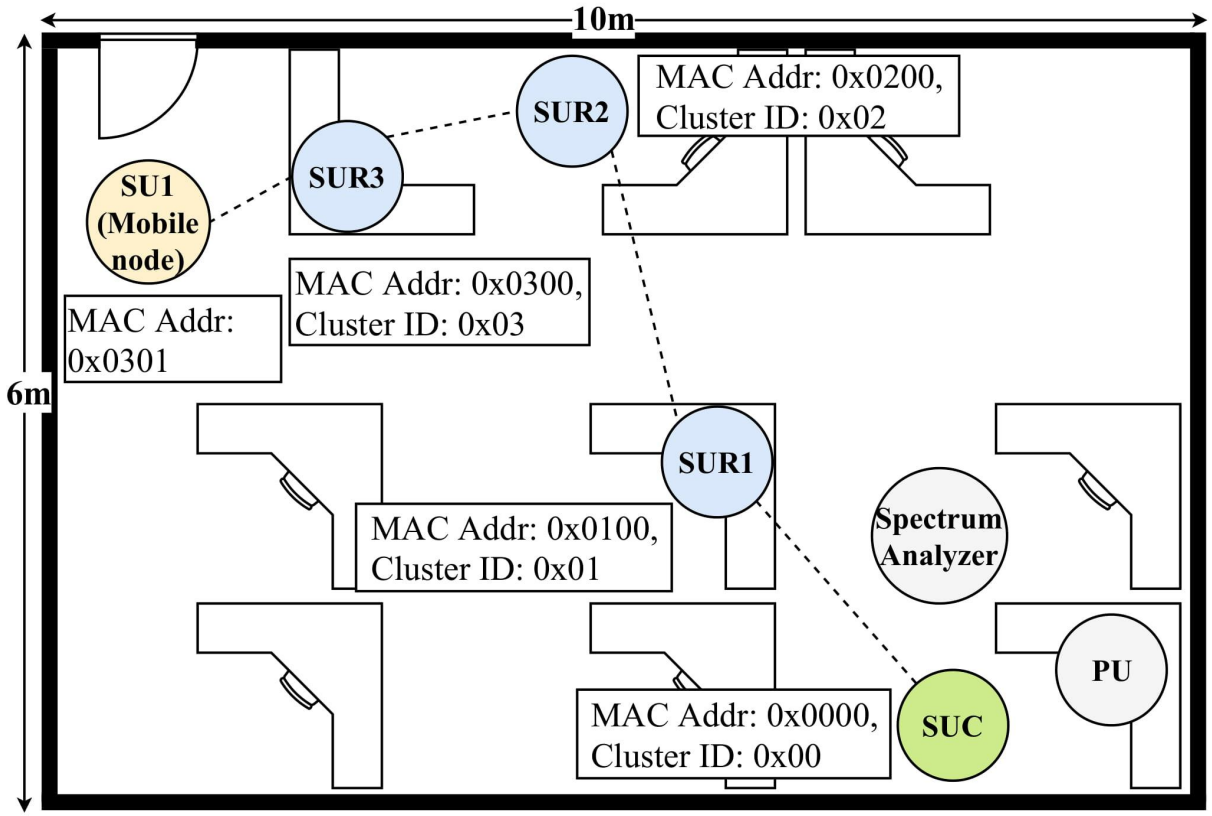




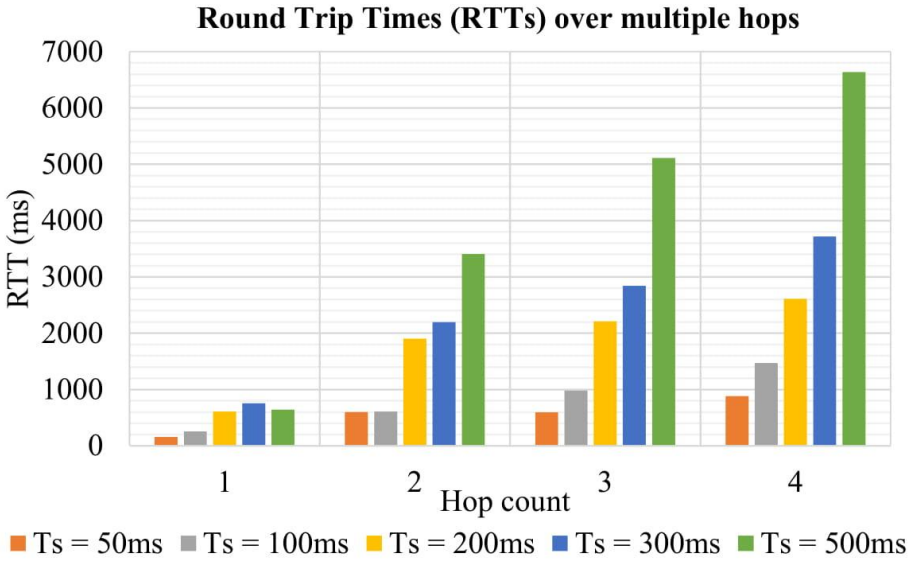
- Under PU activity, MSHCS-MAC still has decent performance while the standard MAC is completely blocked.

5. Demonstration and Evaluation - Multi-hop evaluation

- Each device transmits to SUC over 1 - 4 hops.
- Time sync. accuracy over 4 hops: ~1-2ms.
- Ts = 50-500ms, Tsensing = 10ms, Tbeacon = 5ms, Treporting = 5ms.
- Round trip times and packet delivery ratios are measured at each hop.

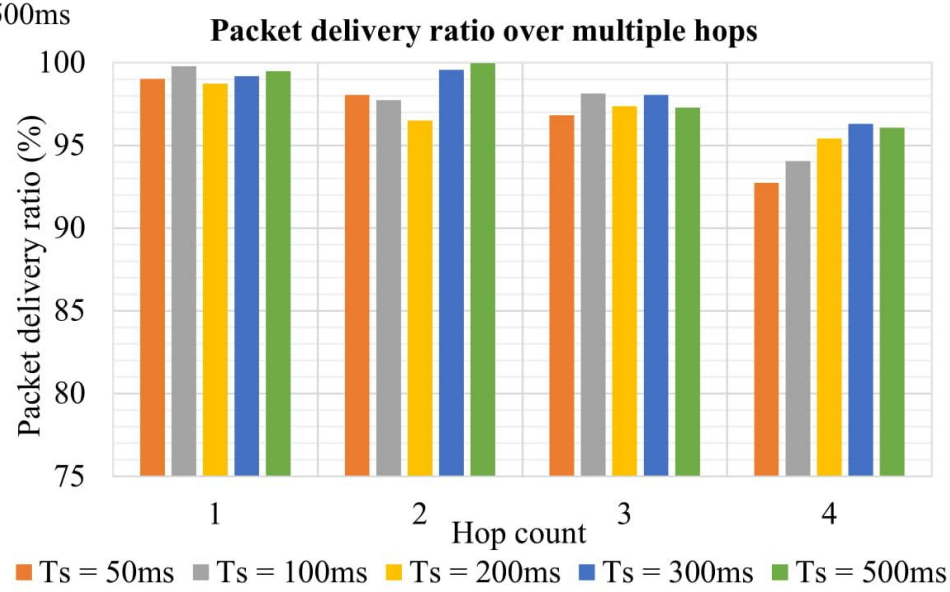


5. Demonstration and Evaluation - Multi-hop evaluation



- Round trip time increases quickly as Ts increases => **lower Ts, better performance.**
- Packet delivery ratios over 4 hops are always > 90%

- Shorter time slot duration (Ts) => lower packet delivery ratio.
- Lower Ts requires more computational power: with Ts=50ms, S8+ get overruned (more samples than CPU can handle) after some time.



6. Conclusions

- **MSHCS-MAC is proposed:**
  - Provide multihop CR communication by exploiting the use of only 1 radio.
  - Better utilize spectrum with independent hopping sequence at each hop.
  - Integration of essential CR-MAC features into a full-blown CR-MAC protocol.
  - Fully functional implementation based on GNU Radio, USRP and available for both PCs and mobile devices.
  - A multi-hop CR networks testbed has been setup to demonstrate and evaluate MSHCS-MAC implementation.
- **Future works:**
  - Optimize time synchronization protocol and performance on mobile devices.
  - Machine learning techniques for spectrum sensing.

Thank You!
QnA?