PHY/MAC Signalling Protocols for Resilient Cognitive Radio Networks

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18/09/2014

Outline

1 Introduction

2 State of the art

3 Spectrum sensing

4 PHY-layer signalling protocol

5 MAC-layer signalling protocol

6 Evaluation

7 Conclusion

8 Bibliography

Cognitive Radio Networks

Current situation

- Exponential growth of the throughput requirement;
- All the Radio Frequency (RF) spectrum has been allocated;
- Not all of it is actually used.

Cognitive Radio Networks (CRN)

- Make use of un-used allocated bands;
- Leave the band when the owner arrives (primary users);
- Secondary users need to gracefuly adapt to RF changes.

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Rendez-vous techniques

Rendez-vous techniques in CRNs

- Common Control Channel [DDSDB12];
- Blind Rendez-vous [LLCL13].

Common Control Channel (CCC)

- Use one channel for node discovery and spectrum allocation;
- May be a bottleneck in dense/large networks;
- May be jammed involuntarily, making the network unavailable.

(Enhanced) Jump Stay [LLCL13]

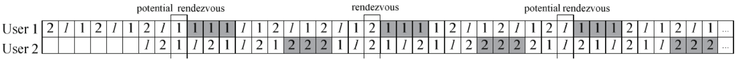

Figure: Overview of the (Enhanced) Jump Stay algorithm [LLCL13]

Problems

- Requires a channel list;
- Does not mix with communication ⇒ No hot-plug to a running network possible.

Physical layer bootstrapping for CRNs [DMPJS10]

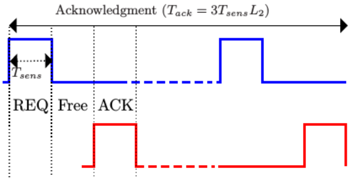

Figure: Overview of the physical-layer bootstrapping algorithm [DMPJS10]

Problems

- Requires a channel list;
- Does not include a discovery mechanism;
- Does not allow multiple transmissions at the same time;
- Over-utilisation of the spectrum to rendez-vous.

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Software radio

Software radio

- Observe a window in a large tunable RF spectrum band;
- Vary the window's size by changing the sample rate.

Nuand's BladeRF [Nua13]

- Tunable band: 300 MHz to 3 GHz;
- Bandwidth: 28 MHz Full duplex (40MSps);
- Price: $420.

Advantages

- Receive/Transmit multiple communications at the same time, as long as they happen in the RF window;
- Software-defined physical layer.

Spectrum sensing - Detecting transmissions

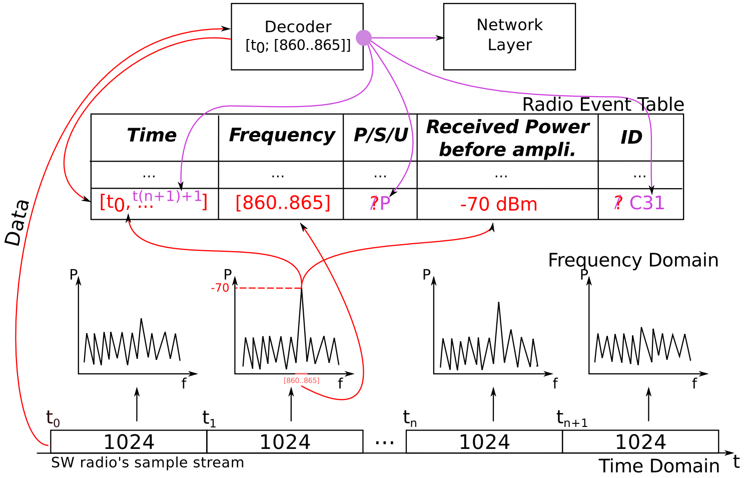

Figure: Overview of the sensing process - Filling the Radio Event Table from the software radio's sample stream

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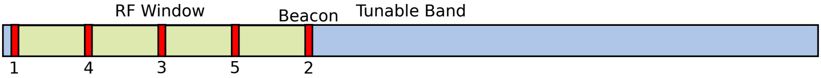
PHY-layer signalling protocol

```
<beacon_frame>{ node_id=23, tx_pwr=10dBm,
[
  { {band1}, len=0.4, period_offset=0.0 },
  { {band2}, len=0.4, period_offset=0.0 },
  { {band3}, len=0.3, period_offset=0.5 },
],
period=1000ms, cur_period_offset=0.126 }
```

Solving the where and when problem!

- Every CR emits a beacon periodically or on demand;
- A beacon contains the hopping pattern of its source node;
- Surrounding CRs know **where** and **when** to contact it;
- The beacon brings a **discovery mechanism**, **time synchronisation** and **channel attenuation assessment**.



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MAC-layer signalling protocol

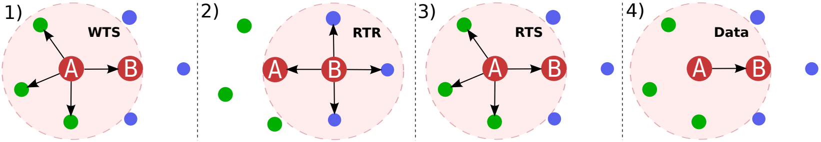

Figure: Overview of the MAC signalling protocol

Willing-To-Send (WTS) frame

- Bands available at the emitter's side (pre-reserve them);
- Modulations supported by the emitting radio;
- Frame size & firm deadline (time until the next hop).

MAC-layer signalling protocol

Ready-To-Receive (RTR) frame

- Band selected by the receiver;
- Modulation selected by the receiving radio;
- Band reservation (neighbours cannot use it until the timeout).

Ready-To-Send (RTS) frame

- Band selected for the frame;
- Modulation selected for the frame;
- Band reservation (neighbours cannot use it until the timeout).

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Experimental setup

```
<beacon_frame>{ node_id=1, tx_pwr=10dBm,
[
  { {band1}, len=0.5, period_offset=0.0 },
  { {band2}, len=0.4, period_offset=0.5 },
],
period=300ms, cur_period_offset=0.45 }
```

Experimental setup

- Two software radios: [300MHz, 3GHz] @ 25 MHz;
- One radio is available on two bands 90% of the time, does sensing the rest of the time.
- The other radio is only performing sensing;
- We evaluate the rendez-vous time.

Impact of the beaconing and hopping period on the TTR

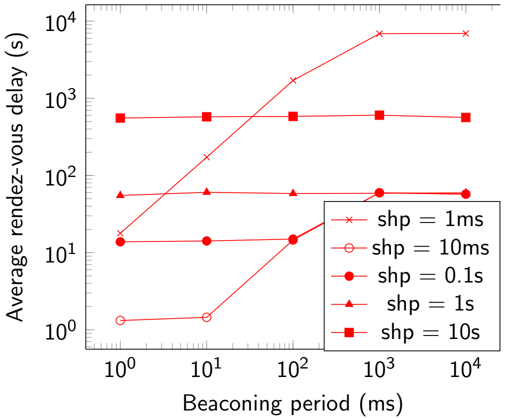


Figure: Influence of the beaconing and sensing-hopping period on the average rendez-vous delay.

Impact of the number of beacons sent on the TTR

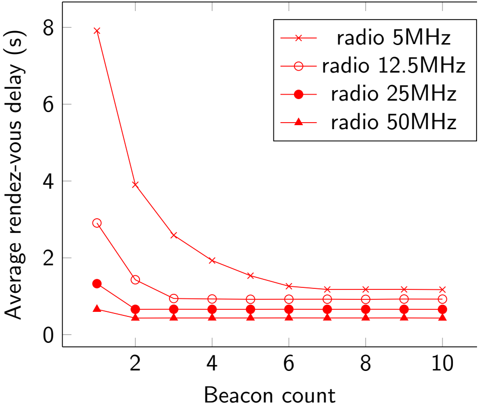


Figure: Influence of the number of beacon sent and the sensing radio's bandwidth on the average rendez-vous delay. shp = 10ms, bp = 10ms

Impact of the sensing radio's bandwidth on the TTR

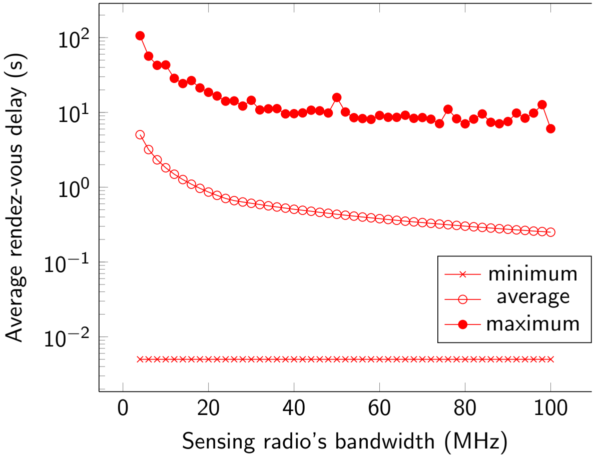
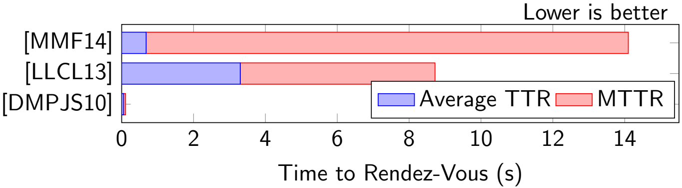


Figure: Variance of the rendez-vous time with shp = 10ms, bp = 10ms, bc = 2, beacon spacing = 24 MHz, 1 million iterations

PHY evaluation: Comparison with the state of the art



[LLCL13] (One time)

- MTTR: $4P * TS$ = 436 * 20ms = 8.72s;
- Average TTR: $3P/2 + 3 * TS$ = 3.3s.

[DMPJS10] (every frame)

- MTTR: $N * T_{sense}$ = 108 * 1ms = 108 ms;
- Average TTR: MTTR / 2 = 54 ms;
- T_{sense} = 1 ms (switching time included).

MAC evaluation: Comparison with 802.11

802.11 control frames

- Our solution is based on 802.11 control frames;
- Our frames are about two times as large;
- The third frame is to lift the reservation of some bands early;
- Just like 802.11, the channel should not always be reserved, depending on the frame's size;
- We did not compare our implementation to 802.11 yet because it is still a work in progress.

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Conclusion & Future work

Conclusion

- Fast one-time synchronisation that can be used to save power by shutting down nodes;
- Does not require a channel/node list or any synchronisation;
- Allows new nodes to enter the network at run time and have concurrent frame transfer.

Future work

- Compress beacons to only keep the time synchronisation, let new CRs ask for the full beacon;
- Validate this work in multiple scenarios on real hardware.

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