Common Control Channel Allocation in Cognitive Radio Networks through UWB Multi-hop Communications

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Problem Definition (1)

Cognitive Radio Networks (CRN) suffer from

- temporal and spatial variations in the radio environment
- changes in Primary User (PU) activities, which may affect several links at the same time
Problem Definition (2)

CR users need a Common Control Channel (CCC) to

1) discover each other and establish a first contact
2) coordinate their access to the spectrum
3) identify common spectrum opportunities to set up data communication on those frequencies

BUT

No channel reservation for common control information

- the availability of any channel is not guaranteed
- different Cognitive Radio (CR) users may be able to access different channels
Problem Definition (3)

Solutions proposed so far in the literature:

- a spectrum portion is reserved for exchanging control information
- no a-priori selected CCC, nodes “meet” by sending in-band signaling on randomly selected channels
  - meeting a specific device with which a node wants to communicate may take a long time
PROPOSED SOLUTION
“Exploit the Ultra Wide Band (UWB) technology to implement the Common Control Channel (CCC)”
Why UWB (1)

- UWB communications cause negligible interference to other narrowband transmissions
- spectrum access through simple Pure/Slotted Aloha protocol
Impulse Radio (IR-UWB)

- uses extremely short pulses with duration of the order of nanoseconds to transmit information
- short pulses have very large bandwidth of the order of a few GHz
- transmission using common and distinct codes
- carrier modulation is not required
- no need of RF power amplifier
- robust to multi-path fading
UWB is a promising solution for the CCC problem. Although it is known to be a short range technology, we observe that

- UWB can reach more than one hundred meters for required data rate of few tens of kilobits per second
- CR nodes that want to exchange data traffic through a medium-range technology (e.g. Wireless LAN) can use UWB multi-hop communication to implement the CCC
UWB Multi-hop Paradigm (2)

As we target a UWB data rate of several hundreds of kilobits per second, then the following relation holds

$$R_{WLAN} = n \cdot R_{UWB}$$

Two types of communication over the UWB CCC
- Direct communication within one-hop UWB (D-CCC)
- Indirect communication within multi-hop UWB (I-CCC)
Communication Protocol (1)

- Using Pure Aloha access scheme
- Discovering the network topology
  - Hello Messages is sent periodically by the users already in the network, using common code
  - Join Request Message (JRM) -Broadcast- using common code
  - Join Answer Message (JAM) -Unicast- using distinct code which is included in the JRM message

**CCC ROUTING TABLE AT NODE A**

<table>
<thead>
<tr>
<th>Destination ID</th>
<th>Next-hop ID</th>
<th>Distance (#hop)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>B</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>C</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>B</td>
<td>2</td>
</tr>
</tbody>
</table>
Communication Protocol (2)

Establishing the data link

A

DHM

DMM

DCM

(D-CCC)

B

A

IHM

IHM

IHM

IHM

IHM

IHM

ICM

ICM

ICM

ICM

(I-CCC)

D

Common code

Distinct code
UWB Channel Model (1)

- Taken from the IEEE 802.15.4a model. Accounts for
  - Free-space and built environment propagation loss
  - Shadowing loss
- The path loss on the link between nodes $i$ and node $j$, whose distance is $d_{ij}$, is
  $$PL_{ij} = PL_0 + 10\eta \log_{10} \frac{d_{ij}}{d_0} + S \quad \text{dB}$$
- Shadowing loss $S$ is log-normal ($\mu = 0, \sigma = 3.96 \text{ dB}$)
- Attenuation exponent $\eta = 1.58, \quad d_0 = 1 \text{ m}$
- The received power at node $j$ is
  $$P_{R,ij} = P_T - PL_{ij} \quad \text{dBm}$$
UWB Channel Model (2)

- The SINR experienced over the link $ij$

$$\text{SINR}_{ij} = \frac{P_{R,ij}}{\sum_{k \in T} P_{R,kj} + N_0 B}$$

where

- $T$ is the set of transmitting nodes at the same time while node $i$ is transmitting
- $N_0$ is the one sided power spectral density of the additive Gaussian noise
- $B$ is the signal bandwidth

- Referring the SINR to the bit energy $E_b$, we obtain

$$\text{SINR}_{ij} BT_b = \frac{E_{b,ij}}{(P_I/B) + N_0} = \frac{E_{b,ij}}{N_I + N_0}$$
The bit error probability can be estimated assuming that interference is a white Gaussian process.

For binary PAM modulation, we obtain

\[ P_{b,ij}(e) = \frac{1}{2} \text{erfc} \left( \sqrt{\frac{E_{b,ij}}{N_I + N_0}} \right) \]
SIMULATION RESULTS
Simulation Settings

- Omnet++ simulator

- $N$ static nodes randomly deployed according to a uniform distribution in a square region of side equal to 250 m

- Each node “feels” the need to start traffic flow according to Poisson distribution, with rate $\lambda$

- In case of failure, CR node will retransmit up to four times and after a random back-off which is picked according to a uniform distribution

- We refer to two CR devices $(i, j)$ as one-hop UWB/WLAN neighbors if their signal-to-noise ratio $SNR_{ij}$ is above a given threshold
Simulation Results (1)

We focus on the communication link establishment between CR nodes over the single-hop D-CCC and the two-hop I-CCC.

![Graph 1: Message Success Probability vs. Per-node flow rate, λ](image1)

![Graph 2: Handshake Success Probability vs. Per-node flow rate, λ](image2)
Simulation Results (2)

The graph illustrates the handshaking probability as a function of the number of users, N. The simulations are run for different values of λ: 0.05, 0.1, and the codebook size for D-CCC and I-CCC. The probability decreases as the number of users increases.
Simulation Results (3)
Simulation Results (4)

D-CCC

I-CCC

PDF of Scc. Handshake

Time Duration [ms]
CONCLUSION & FUTURE WORK
Conclusion & Future Work

- We defined an UWB communication protocol to let cognitive radio nodes discover each other and exchange control information for link set up
- We overcame the gap in coverage that typically exists between UWB and medium-range technologies by using a multi-hop common control channel
- Future work will focus on:
  - Evaluation of the performance of the proposed solution in presence of mobile nodes and different channel access schemes
  - Comparison of the proposed solution against other techniques based on in-band signaling, in terms of success probability, latency in establishing a communication link, and energy consumption
Thank you!