A Dynamic Spectrum Access on SDR for IEEE 802.15.4e networks

Rafik Zitouni, Laurent George[‡] and Yacine Abouda

LACSC laboratory-ECE Paris
‡ UPEMLV, LIGM/ ESIEE Paris

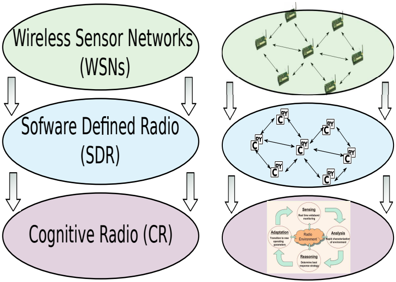
zitouni@ece.fr, ‡laurent.george@univ-mlv.fr and abouda@ece.fr

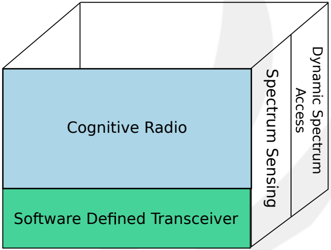
March 23, 2015

Overview

1. Context and Related Works
   - IEEE 802.15.4e
   - Time Slotted Channel Hopping (TSCH)
   - SDR for IEEE 802.15.4
2. Implementation of Dynamic Spectrum Access
   - Experiments and results
3. Conclusion and perspectives

Context and Related Works

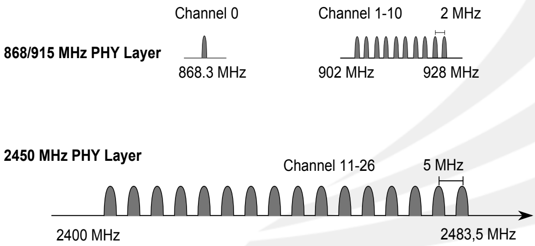




- Dynamic Spectrum Access (DSA) or spectrum sharing is real time adjustments of spectrum utilization. It is based on rewarded information of SS

IEEE 802.15.4e

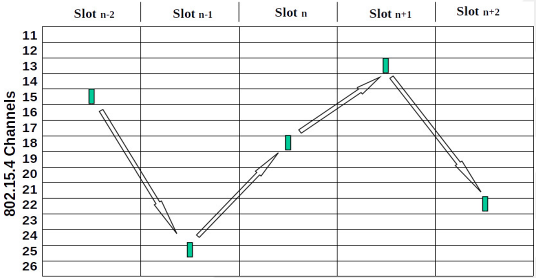
- **IEEE 802.15.4**[1] standard defines PHY and MAC layers for LR-WPAN
  - 2450 MHz O-QPSK (ISM)
  - 868/915 MHz BPSK (ISM)
  - 950 MHz GFSK
  - .etc



[1] working groups, I. S. (2012). *Part 15.4:Low-Rate Wireless Personal Area Networks (LR-WPANSs)*. IEEE Computer Society

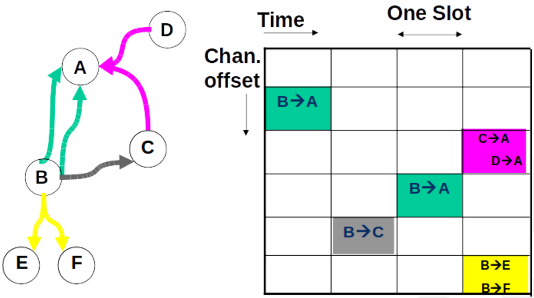
Time Slotted Channel Hopping (TSCH)

- The main new contribution of **IEEE 802.15.4e** is Time Slotted Channel Hopping (TSCH) access mode
  - Allowing distributed implementation with TimeSlotted (One timeslot can be used by multiple links at the same time)
  - Channel Hopping, to give resilience to interference/multi-path fading



Time Slotted Channel Hopping (TSCH)

- Example of Link = (Timeslot , Channel Offset)[2]



- The two links from **B** to **A** are dedicated
- **D** and **C** share a link for transmitting to **A**
- The shared link does not collide with the dedicated links

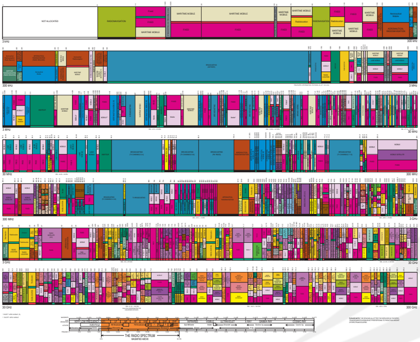
[2] working groups, I. S. (2012). *Part 15.4:Low-Rate Wireless Personal Area Networks (LR-WPANSs).* IEEE Computer Society

Time Slotted Channel Hopping (TSCH)

- Central frequency of each channel is statically defined
- TSCH is proposed only for 2450 MHz band channels
- The channel allocation depends only on the time slots and not on the link quality
    - Link Quality Indicator (LQI) (values from 1 to 255) indicates the energy strength and quality of received data
- TSCH needs a timeslot synchronization and extra acknowledgements transmissions
- Changing dynamically channels in TSCH is not expected without MAC protocol coordination.

Time Slotted Channel Hopping (TSCH)

- In addition Frequency Scarcity



Dynamic Spectrum Access

IEEE 802.15.4e

- Multiple PHY layers with specific frequency bands

PHY (MHz)	Frequency Band (MHz)	Propagation parameters		Parameters of data transmission		
		Chips rate (k chips/s)	**Modulation**	**Bits rate** (kb/s)	**Symbols rate** (k symbols/s)	**Symbols**
780	779-787	1000	O-QPSK	250	62.5	16-ary orthogonal
		1000	MPSK	250	62.5	16-ary orthogonal
868/915	868-868.6	300	DSSS + BPSK	20	20	Binary
		400	DSSS + O-QPSK	100	25	16-ary orthogonal
		400	PSSS + BPSK et ASK	250	12.5	20 bits PSSS
	902-928	600	BPSK	40	40	Binary
		1000	DSSS + O-QPSK	250	62.5	16-ary orthogonal
		1600	PSSS + BPSK et ASK	250	50	5 bits PSSS
950	950-956	—	GFSK	100	100	Binary
		300	BPSK	100	100	Binary
2450 (DSSS)	2400-2483.5	2000	O-QPSK	250	62.5	16 ary-orhogonal
UWB sub gigahertz	250-750					
2450 (CSS)	2400-2483.5	–	CSS + DQPSK	250	62.5	8-ary
				1M	166.667	16-ary bi-orthogonal
UWB low-high band	(3244-4742) (5944-10234)	Depends on environment conditions				

SDR for IEEE 802.15.4

- GNU Radio and USRP SDR platform
  1. GNU Radio transceiver for 2450 MHz O-QPSK [3]
  2. GNU Radio transceive for 868/915 MHz BPSK [4]
  3. Energy detection based Spectrum Sensing [5]
- Proposals:
  - Multi bands and multi specifications SDR
  - DSA throughout two frequency bands
  - Message-based algorithms for dynamic frequency selection

---

[3] Schmid, T. (2006). *Gnu radio 802.15. 4 en-and decoding.* Networked & Embedded Systems Laboratory, UCLA, . . .

[4] Zitouni, R., Ataman, S., George, L., and Mathian, M. (2012). *IEEE 802.15.4 transceiver for the 868/915 MHz band using Software Defined Radio.* SDR Forum

[5] T. OShea, T. Clancy, H. E. (2007). *Practical Signal Detection and Classification in GNUradio.* SDR Forum

Implementation of Dynamic Spectrum Access

Existing DSA techniques are :

1. Dynamic Exclusive Use Model
2. **Open Sharing Model**
   - Two frequency bands of IEEE 802.15.4 network is within unlicensed ISM spectral bands
   - IEEE 802.15.4e network can be considered as Secondary User (SU) of frequency bands whereas all unlicensed networks are Primary Users (PUs)
3. Hierarchical Access

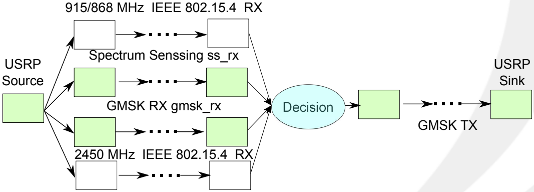
Implementation of Dynamic Spectrum Access

Spectrum Sensing techniques are :

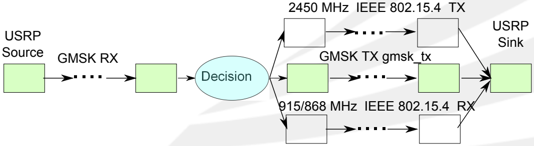
1. **Energy-detector based sensing**
   - Simple to implement on GNU Radio
   - It is based on averaged Power Spectral Density (PSD)
2. Cyclostationarity-Based Sensing
3. Matched-Filtering

Implementation of Dynamic Spectrum Access

- Software Defined Radio Settings
  1. Software chain of SU receiver (Rx)

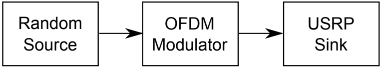


  2. Software chain of SU transmitter (Tx)

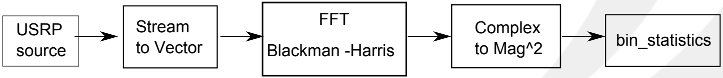


Implementation of Dynamic Spectrum Access

- Software Defined Radio Settings
  3. PU transmitter (Tx)



- Energy-sensor based spectrum sensing



$$E = \frac{1}{2N}\left[\sum_{n=-N}^{N} |s(n)|^2\right] \qquad (1)$$

where N is the number of samples and $s(n)$ is the sample number n

Implementation of Dynamic Spectrum Access

- Dynamic frequency selection

```
initialization();
while energy > threshold do
    spectrum sensing(ss rx)
end while
while not receive_freq_ack(gmsk_rx) do
    send_new_freq(gmsk_tx);
end while
while time ≤ timeout do
    send_clear-to-receive(gmsk_tx);
end while
start_rx_802.15.4(802_15_4_rx);
```

Algorithm 1: Receiver (Rx)

Implementation of Dynamic Spectrum Access

- Dynamic frequency selection

```
initialization();
while not new_freq_received do
    receive_new_frequency(gmsk_rx);
end while
while not clear-to-receive(gmsk_rx) and (time ≤ timeout) do
    send_freq_ack(gmsk_tx);
end while
if clear-to-receive(gmsk_rx) then
    start_tx_802.15.4(802_15_4_tx);
else
    receiver failed to receive clear-to-receive;
end if
```

Algorithm 2: Transmitter(Tx)

Experiments and results

- Three USRP 1 devices, two devices represent SU transmitter (Tx) and receiver (Rx), whereas PU transmitter is the third one
- SBX daughter boards cover two frequency bands 2450 MHz and 868/915 MHz
- For each frequency, the energy sensed is the average of the magnitudes of each bin over 512 samples
- Parameters of energy sensor

USRP sample rate	channel bandwidth	chunk of bandwidth	number of bins	FFT window
4 MS/s	6250 Hz	3 MHz	480	640

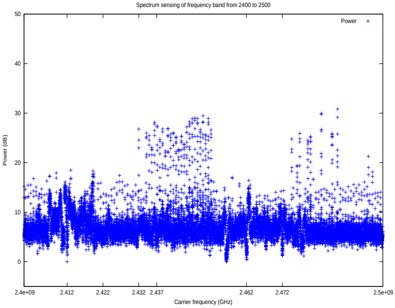
$$\text{fft\_size} = \left\lceil \frac{\text{usrp\_rate}}{\text{channel\_bandwidth}} \right\rceil$$

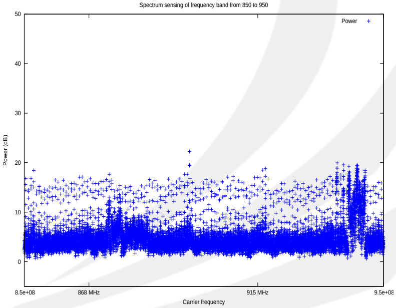
$$\text{bin\_start} = \left\lceil \frac{\text{fft\_size}}{8} \right\rceil$$

$$\text{bin\_stop} = \text{fft\_size} - \text{bin\_start}$$

Experiments and results

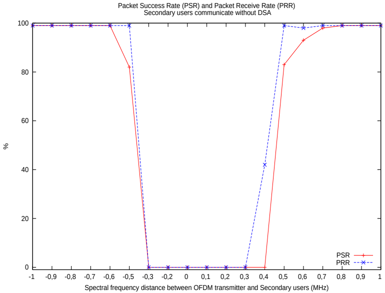
- Spectrum sensor in an indoor environment

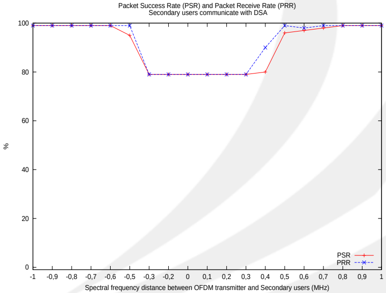




Experiments and results

- Packet Success Rate (PSR) and Packet Received Rate (PRR)





DSA improves PSR by 80% rather than the static frequency selection

Conclusion

- The IEEE 802.15.4 communications chains for 868/915 MHz and 2450 MHz have been combined to obtain DSA scheme
  - The DSA mechanism has been implemented on GNU Radio and USRP SDR platform
  - Communication chains of BPSK, OQPSK, GMSK and energy-sensor receiver have been assembled in one SDR
  - Energy sensor based Spectrum sensing has been carried out with real-world frequency hopping
  - Packet Success Rate (PSR) has been improved by 80 % via DSA mechanism compared to that obtained without DSA

Perspectives

- Define other parameters for frequency band hopping such as criticity levels and reliability of packets' transmission
- Improve the efficiency of our DSA mechanism using machine learning algorithms