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An Energy Efficient Distributed Coordination Function using Bidirectional Transmissions and Sleep Periods for IEEE 802.11 WLANs

Raul Palacios\textsuperscript{a}, Fabrizio Granelli\textsuperscript{a}, Dzmitry Kliazovich\textsuperscript{b}, Luis Alonso\textsuperscript{c} and Jesus Alonso-Zarate\textsuperscript{d}

\textsuperscript{a}University of Trento, Italy
\textsuperscript{b}University of Luxembourg, Luxembourg
\textsuperscript{c}Polytechnic University of Catalonia, Spain
\textsuperscript{d}Telecommunications Technological Centre of Catalonia, Spain
Outline

Problem
- Wi-Fi footprint
- IEEE 802.11 Std. for WLANs
- MAC-layer energy issues

Solution
- Distributed mechanism
- Bidirectional transmissions
- Sleep periods

Results
- Energy efficiency
- Energy consumption
- Traffic load
- Data rate
The Big Picture

- Wide deployment of Wi-Fi hotspots worldwide.
- Increasing diversity of Wi-Fi-enabled devices.

Source: Wireless Broadband Alliance (WBA), Informa, Nov. 2011
Wi-Fi Footprint

- The number of Wi-Fi public hotspots will increase by 350% in 2015.
- Wi-Fi home and hotspots will contribute by 31%-34% to the overall yearly cloud energy consumption, being the second main contributor after mobile networks.
**Wi-Fi Access Points**

- Wi-Fi APs consume up to 4.7 Watts when transmitting data and up to 4.3 Watts when receiving data.
- Wi-Fi hotspots are often heavily loaded and consume a significant amount of energy to offer continuous wireless connection to multiple mobile users.

Source: CREATE-NET, 2012
Wi-Fi-enabled Devices

Laptops and smart phones are the most commonly used Wi-Fi-enabled devices in Wi-Fi hotspots.

Unlike laptops, smart phones are increasingly used year after year.


Source: Jiwire, 2012
Mobile devices are currently equipped with multiple wireless interfaces. Mobile applications that require a huge amount of data, such as Skype and YouTube, contribute to the quick depletion of the batteries.
Nokia N95 Energy Consumption

- Downloading data using the WLAN interface consume significant energy.
- The wireless technologies, and not the CPU or the display, can dominate the energy consumption in some smart phones.

Source: Nokia Research Centre, 2012
Energy Efficiency at the MAC Layer

- **NET**
  - Routing information
  - Reliable data

- **MAC**
  - Transmission Control
  - Channel Status

- **PHY**

  - Takes decisions on the usage of the wireless interface to regulate the access to the channel
  - Best place for energy consumption control and energy saving through cross-layer methods
IEEE 802.11 Standard for WLANs

- **active**: sleep → power save → awake
- **PS mode**: no data to send, listen to beacons, retrieve data
- **DCF**: mandatory, distributed contention, best effort, widely used
- **PCF**: optional, centralised polling, quality of service, rarely used
DCF-Based Channel Access

Basic mode

WLAN AP

1. data

DIFS

2. ACK

SIFS

STA_1

Collision avoidance mode

WLAN AP

1. RTS

DIFS

1. RTSDIFS

SIFS

SIFS

2. CTS

SIFS

3. data

SIFS

SIFS

STA_1

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Atlanta
**DCF: Virtual Sensing and Back Off**

1. RTS
2. CTS
3. data
4. ACK

NAV: RTS + SIFS + CTS + SIFS + DATA + SIFS + ACK

Transmit slot: 4

Backoff = 0

**NAV: DIFS + SIFS + DATA + SIFS + ACK**
**DCF: Limitations**

- Overhead of control packets (RTS, CTS, and ACK)
- Silent periods (DIFS and SIFS)
- Channel sensing and backoff periods
- Collision of packets
Bi-Directional DCF (BD-DCF)

- Simple modification to the rules of DCF
- Right to transmit upon reception of data
- Applied to the AP and any mobile station
- Backwards compatible

BD-DCF-Based Channel Access

Basic mode

1. data
2. ACK + data

Collision avoidance mode

1. RTS
2. CTS
3. data
4. ACK + data
5. ACK
**BD-DCF: Virtual Sensing**

1. RTS
2. CTS
3. data
4. ACK + data
5. ACK + SIFS

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**NAV:**
- RTS + SIFS + CTS + SIFS + DATA + SIFS + ACK
**Bi-Directional Sleep DCF (BDSL-DCF)**

- Exploiting bidirectional transmissions
- Extension of the transmission time
- Duty-cycle in the middle of data exchanges
- Applied to any overhearing mobile station
BDSL-DCF-Based Channel Access

1. RTS
2. CTS
3. data
4. ACK + data
5. ACK

DIFS
SIFS
SIFS
SIFS
SIFS

NAV: RTS + SIFS + CTS + SIFS + DATA + SIFS + ACK

NAV: CTS + SIFS + DATA + SIFS + ACK + DATA + SIFS + ACK

STA_1
STA_2
WLAN AP

NAV for wake-up timer
Simulation Scenario

- Open-source simulator in Python
- Implement DCF, BD-DCF, and BDSL-DCF rules
- Error-free channel
- Data packets of constant length
- Poisson arrival distribution
- All the STAs are within the transmission range of each other
- Equal amount of UL and DL traffic
## Simulation Parameters*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIFS</td>
<td>10 µs</td>
<td>Tail</td>
<td>16 b</td>
</tr>
<tr>
<td>DIFS</td>
<td>28 µs</td>
<td>RTS Size</td>
<td>20 B</td>
</tr>
<tr>
<td>EIFS</td>
<td>86.33 µs</td>
<td>Size of CTS, ACK</td>
<td>14 B</td>
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<td>Slot time</td>
<td>9 µs</td>
<td>MAC Header</td>
<td>34 B</td>
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<tr>
<td>Preamble</td>
<td>16 µs</td>
<td>MPDU Size</td>
<td>1500 B</td>
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<tr>
<td>Signal</td>
<td>4 µs</td>
<td>Data Rate</td>
<td>48 Mbps</td>
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<tr>
<td>Signal Extension</td>
<td>6 µs</td>
<td>Control Rate</td>
<td>6 Mbps</td>
</tr>
<tr>
<td>Duration of RTS</td>
<td>56.33 µs</td>
<td>Transmit Mode</td>
<td>1.65 W</td>
</tr>
<tr>
<td>Duration of CTS, ACK</td>
<td>48.33 µs</td>
<td>Receive Mode</td>
<td>1.4 W</td>
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<tr>
<td>Duration of Data</td>
<td>319.33 µs</td>
<td>Idle Mode</td>
<td>1.15 W</td>
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<tr>
<td>Sleep Time</td>
<td>217 µs</td>
<td>Sleep Mode</td>
<td>0.045 W</td>
</tr>
<tr>
<td>Sleep &lt;-&gt; Idle Time</td>
<td>250 µs</td>
<td>Sleep -&gt; Idle Mode</td>
<td>1.73 W</td>
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<tr>
<td>CW&lt;sub&gt;min&lt;/sub&gt;, CW&lt;sub&gt;max&lt;/sub&gt;</td>
<td>16, 1024</td>
<td>No. of STAs</td>
<td>20</td>
</tr>
<tr>
<td>Service</td>
<td>6 b</td>
<td>Simulation Time</td>
<td>15 s x10 times</td>
</tr>
</tbody>
</table>

*IEEE 802.11g*
Transitions between Sleep and Idle

Network Energy Efficiency

- DCF
- BD-DCF
- BDSL-DCF $\alpha=2$
- BDSL-DCF $\alpha=1.5$
- BDSL-DCF $\alpha=1$

Network energy efficiency (Mb/J) vs. Total offered traffic load (Mbps)

- 75%
- 102%
- 142%
AP’s Energy Efficiency

![Graph showing AP’s energy efficiency versus total offered traffic load (Mbps). The graph compares different protocols: DCF, BD-DCF, BDSL-DCF α=2, BDSL-DCF α=1.5, and BDSL-DCF α=1. The y-axis represents AP’s energy efficiency in Mb/J, and the x-axis represents total offered traffic load in Mbps. The data is scaled by a factor of 10.]
Unfairness in the Downlink

With the proposed BD-DCF/BSL-DCF protocols, bottlenecks are resolved.

WLAN AP

STA_1

STA_2

STA_3

STA_4

With the DCF access method, unfairness is observed.
Average Per-Station Energy Efficiency

![Graph showing average per-station energy efficiency against total offered traffic load. The graph compares DCF, BD-DCF, and BDSL-DCF with different values of α (α=2, α=1.5, α=1). The graph highlights improvements of 11% and 35% respectively at certain traffic loads.]
DCF: Network Energy Consumption

Distribution of energy consumption (%)

Total offered traffic load (Mbps)

idenergy
rxenergy
txenergy
BDSL-DCF: Network Energy Consumption

Distribution of energy consumption (%)

Total offered traffic load (Mbps)

- slenergy
- idenergy
- rxenergy
- txenergy
BDSL-DCF: Network Time Distribution

Distribution of time (%)

Total offered traffic load (Mbps)

- sltime
- idtime
- rxtime
- tctime
BDSL-DCF: Maximum Network Energy Efficiency Gains

Percentage of maximum energy efficiency gain (%)

PHY data transmission rate (Mbps)

- 54 Mbps: 69.28%, 96.49%, 133.96%
- 48 Mbps: 75.24%, 102.68%, 142.34%
- 36 Mbps: 93.55%, 123.72%, 163.68%

Legend:
- α=2
- α=1.5
- α=1
Summary

- BDSL-DCF is a new MAC protocol based on DCF.
- BDSL-DCF enables bidirectional communications.
- BDSL-DCF reduces the overhead of control packets, the time for channel contention and the collisions of packets.
- BDSL-DCF better balances transmission opportunities between the AP in the downlink and the STAs in the uplink.
- BDSL-DCF allows overhearing STAs to enter the sleep mode during ongoing transmissions, in a packet-per-packet basis, to conserve energy.
- BDSL-DCF improves throughput up to 30.08% and energy efficiency up to 163.68%. The maximum gain in energy efficiency increases when the data rate decreases.
- Ongoing work: Analyzing and implementing BDSL-DCF on MAC-reconfigurable FPGA platforms and developing an ns-3 simulator to verify the obtained results with our own simulator.
Thanks for your kind attention!

Raul Palacios
raul.palaciostrujillo@disi.unitn.it
www.fp7-greenet.eu