On the Energy Efficiency of Opportunistic Access in Wireless Home Networks

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Is ICT a Green Technology?

- ICT and computing resources account for
  - 3% to 10% of the worldwide energy consumption
  - 2.5% of the global carbon dioxide (CO_2) emission (will be 4% in 2020)
    - ICT CO_2 emission is approximately equivalent to that of airplanes and 1/4 that of automobiles worldwide.

- ICT players are currently aiming at reducing CO_2 emission by favoring less energy consuming technologies to maintain a sustainable ecosystem

Wireless Home Networking (WHN)

- The demand for home networking is surging
- The number of home devices with IEEE 802.11 interfaces in 2014 exceeded **one billion** devices*

Source: http://www.conceptdraw.com/

* ABI Research, "Wi-Fi continues to dominate one billion unit home networking equipment and networked-enabled media device market."

Current WHN Channel Management

- Manual and Static:
  - Fixed IEEE 802.11 channel per WHN application

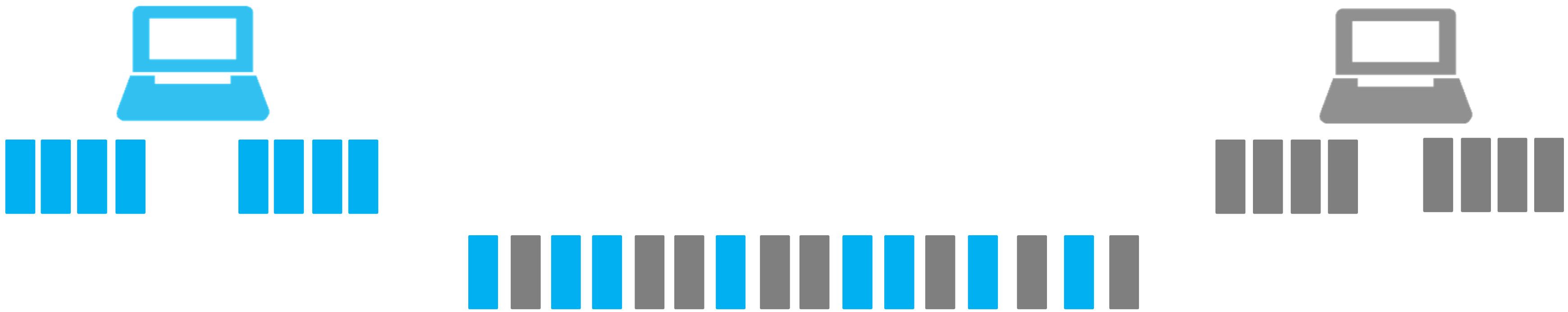
WHN App	Channel #
Multimedia Streaming	1
Wireless Speaker	6
Smart Light Control	11
Smart Energy Control	4
……	….

- Dynamic and Periodic:
  - WHN periodically changes its operating channels after **predefined** time intervals

- Problem: As no. of WHN increases, multiple WHN applications may coexist on a given channel
  - How they will share the channel??

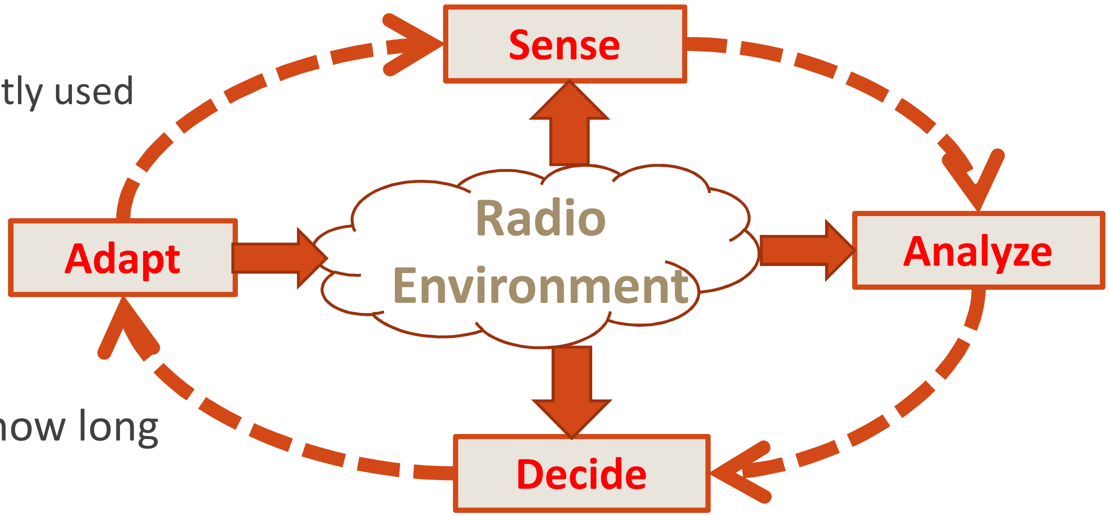
Contention-based Coexistence

- Standard IEEE 802.11 MAC
  - CSMA/CA listen-before-talk
  - No differentiation between two competing networks
    - Both networks will have the same channel access right
    - Equal bandwidth under fully backlogged traffic conditions



Opportunistic Access Coexistence

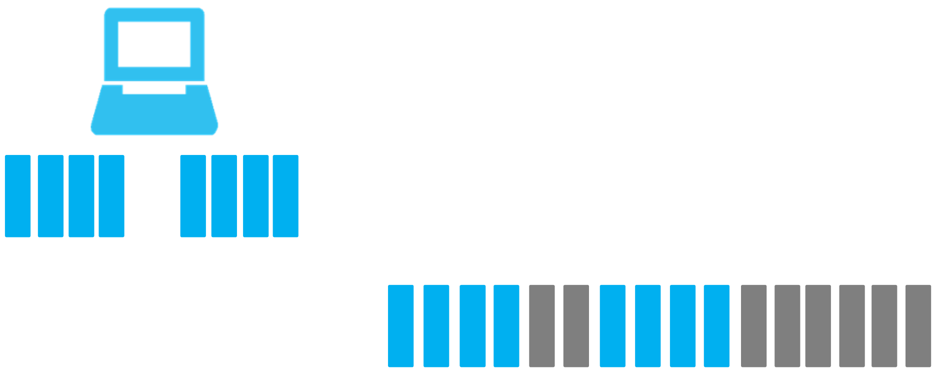
- Integral concept of cognitive radio communication
- Channel Awareness
  - A WHN network uses a channel that is not currently used
- Based on Channel Sensing
- Ability to decide which choose and when/for how long



J. Mitola III, “Cognitive radio: an integrated agent architecture for software defined radio,” Ph.D. Thesis, KTH Royal Institute of Technology, 2000

Opportunistic Coexistence in WHNs

- Achieves autonomous channel and smart management
- Allow prioritizing channel access
  - Primary networks (high priority) and secondary networks (low priority)
  - Provides guarantees on the performance of the primary networks



Objectives

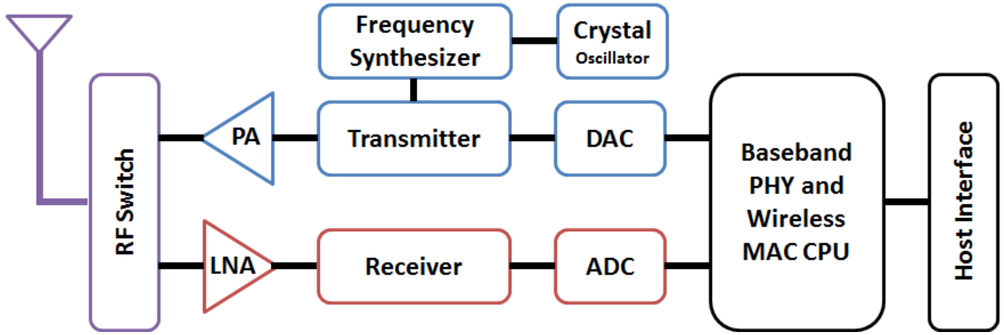
- Empirically assess opportunistic access from **energy** point of view if used in WHN
- Would it be more energy-efficient to have WHN applications opportunistically sharing a channel instead of competing for access?
  - Prioritizing WHN applications
  - Allowing low priority WHNs to access the channel only when not used
- Only one channel (statistical multiplexing gain of channel gain is not considered)
- Evaluate basic opportunistic access energy gain **not a particular energy-efficient protocol**
- Simple modifications to commodity WHNs wireless IEEE 802.11 chipsets

Energy Consumption of Radio Transceivers

- TX Power & RX Power
  - Depend on modulation scheme, the coding rate, the antenna configuration, …
  - Comparable but their absolute values differ from one implementation to another

- IDLE Power
  - Measurement studies show that it is still comparable to the TX and RX powers
  - When in the idle mode, it still down-converts the RF signal, sample and process it.

- SLEEP Power
  - Order of magnitude less than the above powers



Methodology

- Implement opportunistic access using commodity IEEE 802.11 chipsets
  - A Secondary device can only access the channel only if the primary has no packets to transmit

- Candidate IEEE 802.11 parameters
  - Increase the sensing duration of the lower priority device
  - Increase the binary exponential backoff (BEB) parameters of the secondary device
    - No strict guarantees since it is probabilistic in nature

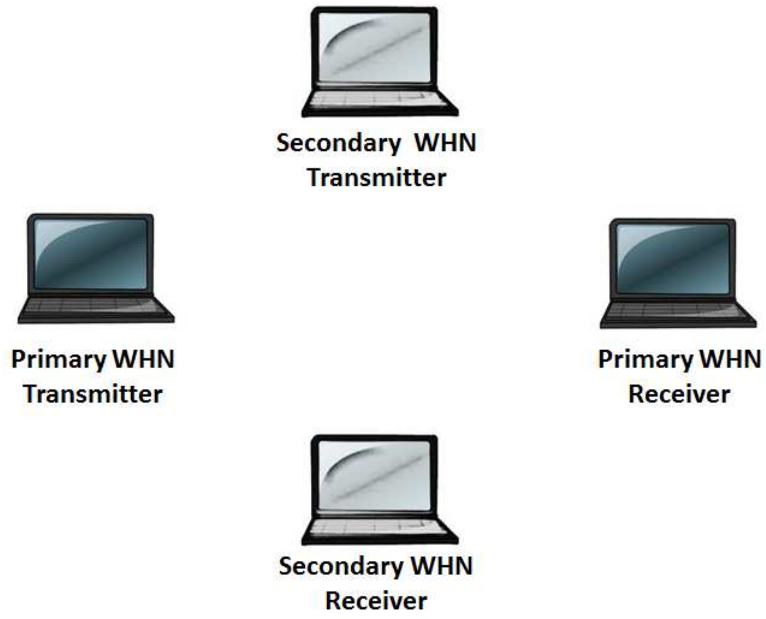
- Arbitration Inter-Frame Spacing (AIFS): is the time a node waits before transmitting next frame

$$AIFS = SIFS + AIFS_{number} \times \text{Slot time}$$

- Accordingly modify the open source *Ath9k* driver developed for all Atheros IEEE 802.11 chipsets

Experimental Methodology

- 1 flow per network
  - Resembles the aggregation of all the traffic of arbitrary no. of in range flows in the network
- Primary Network (High Priority)
  - ON/OFF periodic traffic
  - Activity Factor: fraction of ON time
- Secondary Network (Low Priority)
  - Fully backlogged traffic
  - Use the modified driver

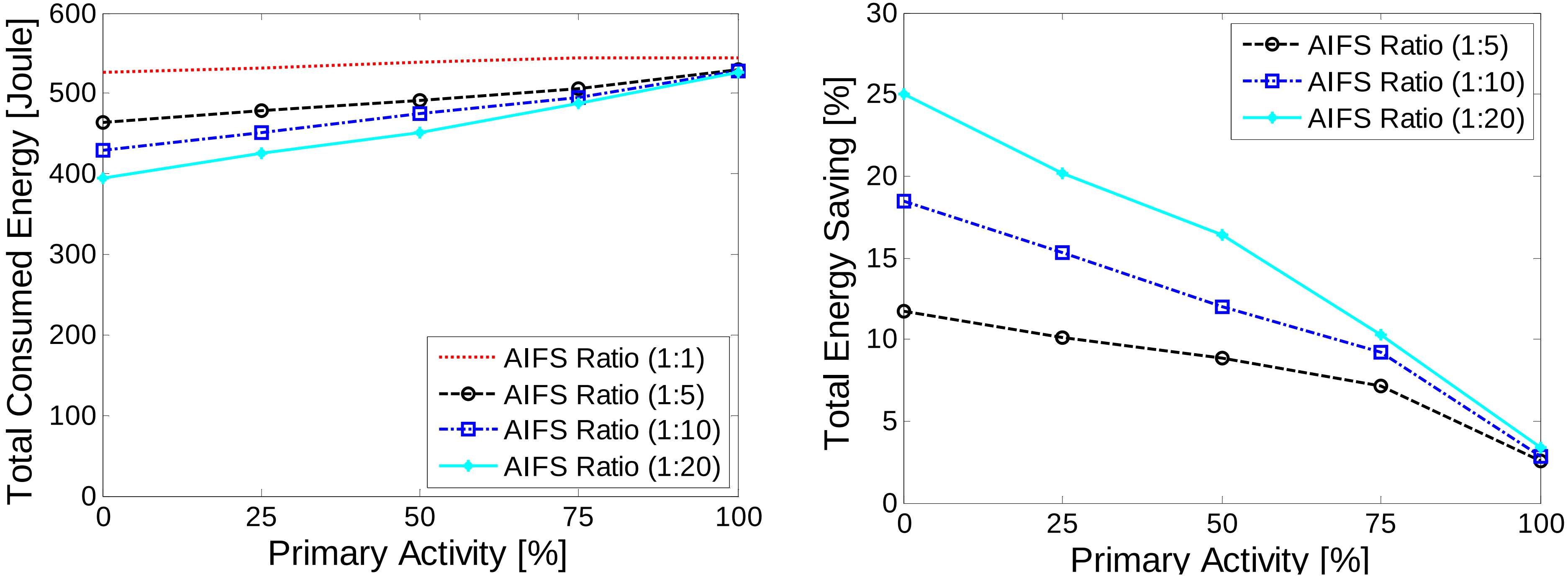


Experimental Setup

Parameter	Value
UDP Packet Size	1470 Bytes
Chipset	AR9285
PHY Rate	54 Mbps
SIFS	16 μsec
AIFS	34 μsec
Slot Time	9 μsec
(CW_{min}, CW_{max})	(15, 1023)
Chipset Voltage	3.3 V
TX Power Consumption	1531.2 mW
RX Power Consumption	1551 mW
IDLE Power Consumption	696.3 mW
SLEEP Power Consumption	23.1 mW

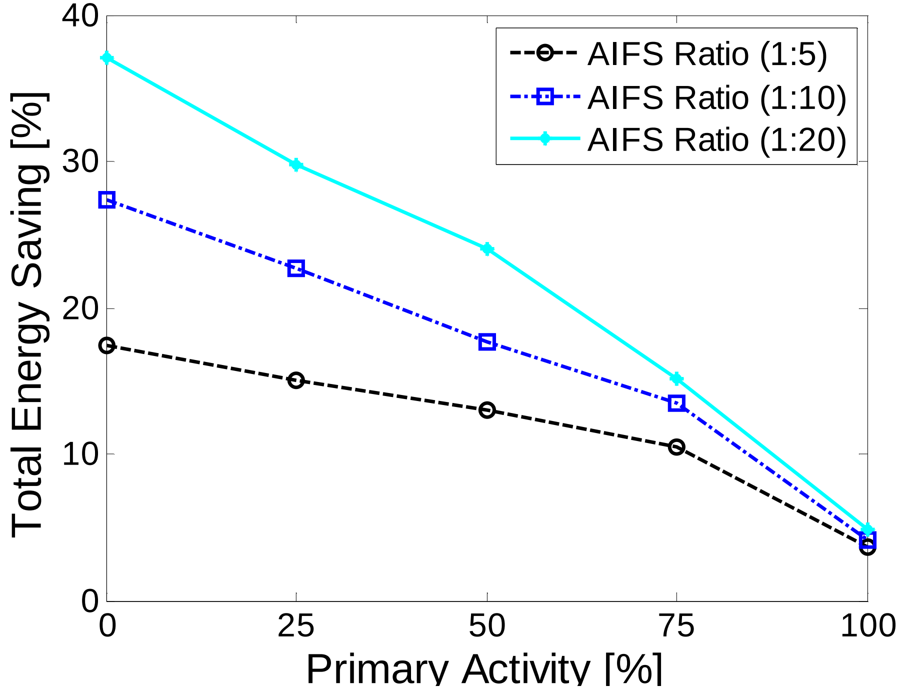
- *iperf* to generate and collect traffic
- Channel 10 was used as its least interfered channel
- Experiments were conducted at early hours of morning
- Average of at least five independent runs, each of 120 seconds length

Opportunistic Access Energy Saving



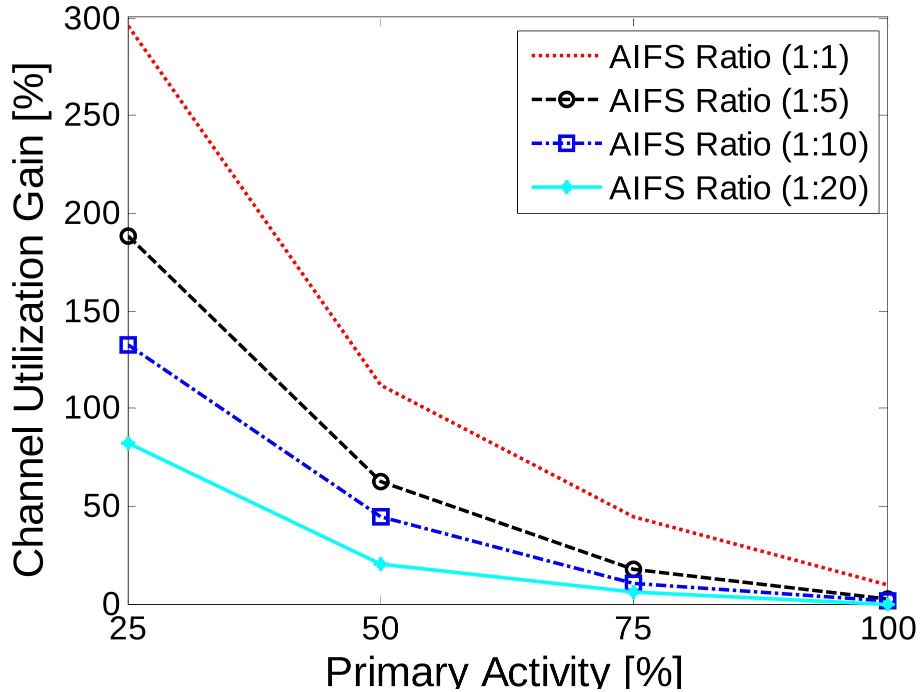
- Opportunistic access achieves energy saving up to 25% that decreases with AIFS reduction.

Opportunist Access with Low Power IoE Chipset (QCA4004)



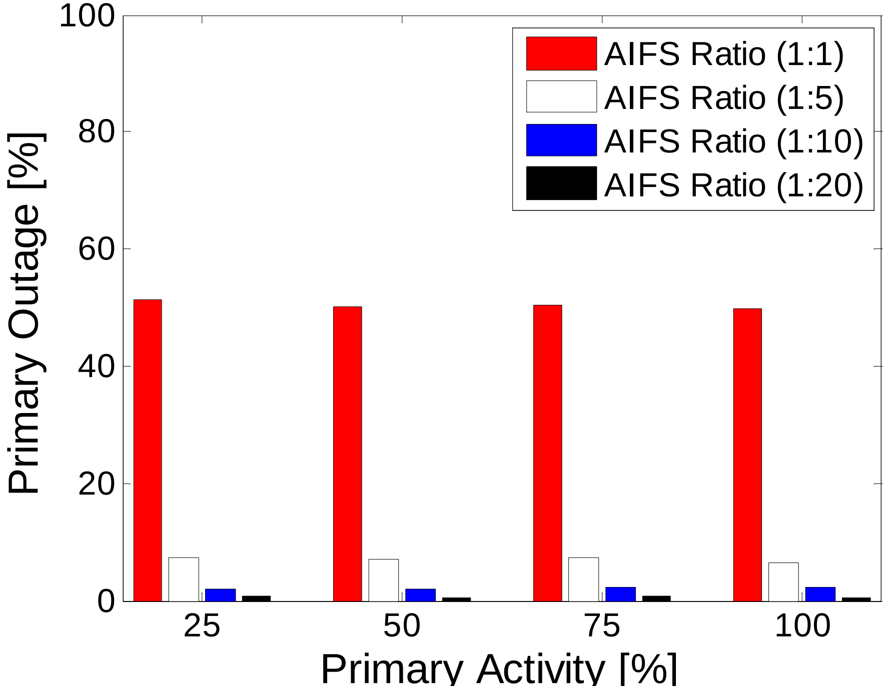
- The energy saving of opportunistic access increases up to 40% with low power chipsets

Channel Utilization



- Opportunistic access significantly improves the channel utilization, however, its gain is below contention-based access

Impact on Primary Network Outage



Another laptop equipped with *Wireshark* packet sniffer

- AIFS Ratio controls the protection level of the primary network (6.4% to 0.5%) which is significantly better than contention access (~50%) regardless the activity pattern of the primary network

Conclusions

- Opportunistic Access is not only a spectrum-efficient mechanism but also **energy efficient**
- Such energy efficiency depends on the TX/RX/IDLE power profile of WHN wireless chipset
- IEEE 802.11 parameters can be configured to implement opportunistic access
- There is a trade of between energy efficiency and the outages caused to primary WHNs

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