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The effects of WiFi off-loading access on energy consumption & emissions in 3G / LTE wireless networks, and derived "green tariff" issues

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Short definition of Wi-Fi off-loading

- Mobile Internet and some other major data applications drive public 3G/LTE networks to saturation (in built-out and build-up phases alike)
- WiFi off-loading is the use of IEEE 802.11x transceivers to capture part of the access data traffic in high teledensity environments, for concentration and/or relay
- User equipments (for data) are either dual stack WiFi/ LTE(3G) wireless modems, or separate modems with hand-over (UMA etc)
- Different spectral bands are assumed, one at least of which is licensed, as well as advanced interference rejection and adaptive signal control

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Research questions

- As the energy efficiency and range of WiFi communications technology are significantly less than those of 3G/LTE access concentration, to which extent should Wi-Fi offloading take place?
- What are the trade-offs, taking lesser WiFi equipment cost into consideration?
- Offer a tool for industry to assess energy costs, measure impact on « *green* » *telecommunications tariffs* and profitability

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Modelling approach

Reuse and extend an earlier HPC model (see COST 804 Coimbra):

- Tool developped for industry, giving a quasi-real *network infrastructure and traffic model*, with energy footprints for all main subsystems (radio, transmission , cooling) and traffic dependent energy consumption (circuit switched and IP);
- Includes *economic sub-models* of CAPEX, OPEX, Billing, CRM, Network management, Content acquisition , on the basis of the *marginal flows* linked to one additional user, on top of an existing subscriber base; use of estimated Cobb Douglas functions;
- Includes *energy consumption* , CO2 *emissions* and *renewable energy supply sub-models* on the basis of marginal flows linked to one additional user
- Retain user led individualized service selection and tariff bidding processes (generric and value-added services)

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Infrastructure

- UTRAN (Radio): RBS* etc.. for:GSM/GPRS, EDGE/HSPDA , LTE (100 Mb)
- Transmission: line cards*, Microwave links*, ATM over IP*, WDM , SONET
- Backbone: MGW*, edge routers*, core routers*, AAA, signalling
- Storage : CDR , billing / CRM data , on-demand media, regulated security records
- Power: electrical grid power, local wind power, local sun power , backup local power
- Cooling: (*)
- Network capacity adapted to meet QoS thresholds given subscriber bids (incl, service mix); excess capacity not used by generic services may be used by value-added services ; if it is insufficient, extra capacity provisioned by SLA at higher rates

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Subsystem data

- Real technical data (power, volume, voltage, frequency, performance) used in most cases from 8 different worlwide suppliers, for different technologies / generations
- Real cost, power usage and investment data cross-validated between three public international operators
- When relevant statistical regression estimated or usage of different research groups approximation formula from physical measurements

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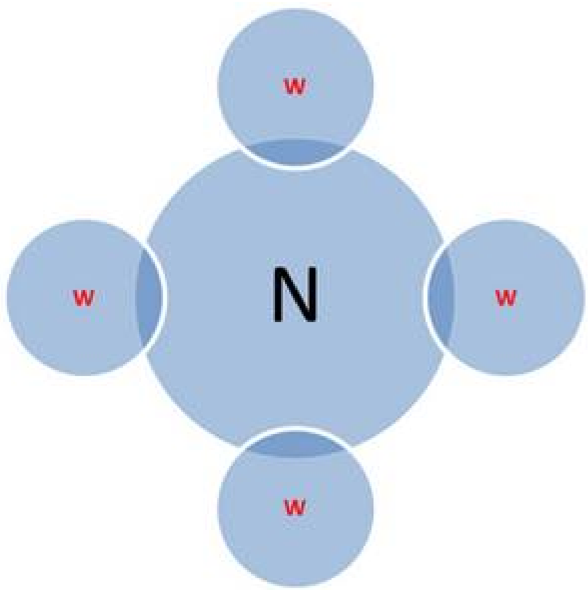
WiFi off-loading by backhaul coverage effect

N	**N**	**N**
N	W	**N**
N	**N**	**N**

N: Node-B/ eNode B
W: WiFi Base station

- If the RBS-to-nearest-RBS distance is *less* than the maximum range of a WiFi Base station, it is possible to let this WiFi Base station serve as a partial dynamic relay off-loading such RBS's
- Omni-directional geometry is assumed
- Implementation details (configuration , protocols , network management) are technology specific; 5 GHz 802.11n is one option

WiFi off-loading by small cell mesh traffic off-load effect



N: Node-B/ eNode B
W: WiFi Base station

- If the RBS-to-nearest-RBS is larger than the WiFi Base Station maximum range, the benefit of WiFi is in off-loading traffic in the close neighborhood of the RBS location
- The radius of this neighborhood must be such that the WiFi Base station data rate can still be sustained (typically 48 MB/s for 802.11.g (eventually boosted)).
- Omnidirectional geometry assumed
- Implementation details (configuration , protocols , network management) are technology specific

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Other trade-offs

- Possible reduction in Node-B sites, and thus CAPEX, OPEX and energy consumption
- Possible reduction in needed Node-B capacity when traffic off-load applies, with normally corresponding in CAPEX, OPEX and energy consumption
- Addition of, or increase in WiFi Base Station numbers, with corresponding CAPEX , OPEX , network management and energy consumption additions
- Possible increase in data capacity per cell from WiFi Base stations, if Node-B numbers and designs remain unchanged
- The combination of these effects is still measured by the *energy consumption* (and CO2 *emissions*) linked to an incremental user , with a user-specified service demand and individual tariff, over the contract duration.

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Base case : Wide coverage

- Coverage: 500 x 500 km
- Teledensity: 1 Million users
- Technologies: GSM, 3G, HSPDA, LTE with WiFi Base station offload
- RBS (or equivalent function) coverage: 5 km radial
- WiFi Base Station: 802.11.b/g/n, range 150 m, omnidirectional antennas, 48 Mbit/s peak data rate
- Duration: 1 year
- Content provisioning: none, but content provisioning available and operational
- Services: generic (voice, SMS, capped Internet)
- ARPU/month : 40 Euros (480 Euros for duration)

Example

WiFi Traffic offload (in % of cells)	Incremental energy consumption for period for one additional user (W)	Incremental emissions for period for one additional user (kg CO2)	Incremental CAPEX with amortization (Euros)	Incremental OPEX with amortization (Euros)	Incremental operator profit (in Euros)	Energy costs/ OPEX (%)
10	207145	81,4	29,12	144,63	333	11,4
20	207247	81,4	31,90	147,42	330	11,2

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Base case : Hot spot with Femto Base station coverage

- Coverage: 5 x 5 km
- Teledensity: 1 Million users
- Technologies: GSM, 3G, HSPDA, LTE with WiFi Base station offload
- RBS (or equivalent function) coverage: 0,2 km radial
- WiFi Base Station: 802.11.b/g/n, range 200 m, omnidirectional antennas, 48 Mbit/s peak data rate
- Duration: 1 year
- Content provisioning: none, but content provisioning available and operational
- Services: generic (voice, SMS, uncapped Internet)
- ARPU/month : 40 Euros (480 Euros for duration)

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Example

WiFi Coverage offload (in % of cells)	WiFi Traffic offload (in % of cells)	Incremental energy consumption for period for one additional user (W)	Incremental emissions for period for one additional user (kg CO_2)	Incremental CAPEX with amortization (Euros)	Incremental OPEX with amortization (Euros)	Incremental operator profit (in Euros)	Energy costs/ OPEX (%)
0	50	54817	21,5	13,04	114,59	364	3,83
20	50	50062	19,7	12,66	113,73	365	3,52
50	5	43114	16,9	12,10	112,47	366	3,07

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Wi-Fi off-load Results (I)

- General: There are very many interactions to account for
- Wide area coverage: Due to lower energy efficiency / transmitted MB and much lesser coverage, using WiFi off-load, is not an interesting alternative: impact on energy consumption is minimal, whereas OPEX and CAPEX grow fast, even though profits are not too much affected. Furthermore, in 2,4 MHz band, there may be interference and security issues
- Hot spot usage: There is huge energy reduction derived , dependent however on the extent to which coverage off-load is used (20 % energy and emissions reduction per incremental user when using just half of the coverage off-load effect).The coverage effect's energy impact is far greater than traffic off-load , in the presence of coverage off-load. CAPEX is reduced by about 10 % while OPEX and profits stay unchanged.

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Wi-Fi off-load Results (II)

- Scenario comparison: emissions are halved, and energy consumption is ¼, while profits increase, if *hotspot* operations are chosen .The dependence on power utilities is also reduced.
- Conclusions:

1. WiFi Base station off-load by the traffic effect is not interesting, until WiFi Base station data rates are not vastly increased.
2. Operators are , for energy / emissions reduction but also profits , advised to migrate to mixed RBS and WiFi Base station offload configurations in hotspot / high teledensity environments
3. Much technology progress is missing from WiFi Base station designs in terms of energy efficiency vs. performances .
4. The relevance of reneweable energies is limited to wide-area coverage where the share in OPEX of energy costs is the highest; new WiFi backhaul designs can operate on solar power

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Deployments for Wi-Fi off-load

- Office buildings with heavy data traffic and reloceable desks
- Homes with convergence access routers
- WiFi Base stations on lightpoles
- Real time information services, e.g. bus arrivals

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Green tariff impact

- The very profitable small cell off-load offers room for not only tariff incentives, but also technology migration of WiFi access modems to lesser energy consumption types (current designs can draw 8 W peak)