Green Mobile Backhaul in Heterogeneous Wireless Deployments

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Outline

• HetNet deployment and role of BH
• Case study with different HetNet solutions
  - Macro BS + pico BS: outdoor deployment
  - Macro BS + femto BS: indoor deployment
• BH power consumption assessment
• Conclusions
Energy efficiency becoming a priority in mobile broadband access

- Mobile broadband data usage is experiencing a dramatic growth

- Power consumption will increase to keep up with traffic demand
- Energy prices increase (expected: 3x in 7 years)
- Clear challenge ahead: meeting the expected 2020-2025 traffic levels maintaining current/low power consumption figures
Possible solution: HetNet deployments

- HetNet is an alternative to macro cell densification
- Rationale: tailor network deployment to the expected traffic levels
  - selectively add small high-capacity BS only where it is needed (hotspots)
- Result
  - smaller cell sizes (advantageous path loss)
  - capacity provided by macro cells
  - coverage provided by Pico/Micro/Femto BS
HetNet deployment – an example
HetNet: role of backhaul unclear

- Most studies consider only the aggregated power consumption of the base stations
- Contribution of the backhaul to the total network power is omitted/neglected
- Analysis of the power consumption for HetNet deployment scenarios including the effect of BH is needed
- Two HetNet case studies are considered:
  - macro + pico: outdoor deployment
  - macro + femto: indoor deployment
Case study: HetNet outdoor deployment

Cost (i.e., $) effective HetNet deployment for a area of $4 \times 4$km with 3G UMTS macro and pico BS

- Each BS type assumed to have
  - maximum supported throughput $s_{\text{max}}$ [Mbps/km²]
  - maximum range $\delta_{\text{max}}$ [km]
- Number of base stations required is determined sequentially
  - macros are deployed first to provide coverage
  - picos added where extra capacity needed
- Two BH technologies: MW and fiber

- Peak user downstream data rate of 100Mbps in total

Traffic backhauled through a *hub* node connected to an area aggregation point, i.e., *sink* node

- Single/multiple hubs, function of topology and architectural choice
- If multiple backhaul links originates or terminate at a node, *switch* is needed
- *Ring*: good for resiliency, latency might me an issue, limited number of sites because of capacity issues
- *Star*: simplest one, might have LOS limitation for MW links
- *Tree*: sensitive to faults to feeder links, better delay than ring
MW-based backhaul power model

\[ P_{\text{tot}}^{MW} = \sum_{i=1}^{m} N_i P_i + P_{bh}^{MW} \]

\[ P_i = a_i P_{tx} + b_i \]

\[ P_{bh}^{MW} = P_{\text{sink}} + \sum_{j=1}^{N_{BS}} P_j^{MW} \]

\[ P_j^{MW} = P_{j,\text{agg}}(C_j) + P_{\text{switch}}(N_{j}^{\text{ant}}, C_j) \]

\[ P_{j,\text{agg}}(C_j) = \begin{cases} P_{\text{low-c}}, & \text{if } C_j \leq T_{\text{low-c}} \\ P_{\text{high-c}}, & \text{otherwise} \end{cases} \]

\[ P_{\text{switch}}(N_j^{\text{ant}}, C_j) = \begin{cases} 0, & \text{if } N_{j}^{\text{ant}} = 1 \\ P_S \left( \frac{C_j}{C_{\text{MAX}}^{\text{switch}}} \right), & \text{otherwise} \end{cases} \]

\[ P_{\text{sink}} = P_{\text{sink,agg}}(C_{\text{sink}}) + P_{\text{sink,switch}}(N_{\text{sink}}^{\text{ant}}, C_{\text{sink}}) \]

\[ P_{\text{sink,agg}}(C_{\text{sink}}) = \begin{cases} P_{\text{low-c}}, & \text{if } C_{\text{sink}} \leq T_{\text{low-c}} \\ P_{\text{high-c}}, & \text{otherwise} \end{cases} \]

\[ P_{\text{sink,switch}}(N_{\text{sink}}^{\text{ant}}, C_{\text{sink}}) = \begin{cases} 0, & \text{if } N_{\text{sink}}^{\text{ant}} = 1 \\ P_S \left( \frac{C_{\text{sink}}}{C_{\text{MAX}}^{\text{switch}}} \right), & \text{otherwise} \end{cases} \]

Fiber-based backhaul topology and power model

\[ P_{\text{tot}}^{\text{FIB}} = \sum_{i=1}^{m} N_i P_i + P_{\text{bh}}^{\text{FIB}} \]

\[ P_i = a_i P_{tx} + b_i + c_i \]

\[ P_{\text{bh}}^{\text{FIB}} = \left[ \frac{1}{C_{\text{switch}}^{\text{MAX}}} \left( \sum_{i=1}^{m} C_i \right) \right] P_s + \left( \sum_{i=1}^{m} N_i \right) P_{dl} + N_{ul} P_{ul} \]

Backhaul power consumption: MW vs. Fiber

- Macro + Pico case
- Two scenarios: small size (left) and large size microwave topologies (right)

Backhaul impact on total network power consumption: outdoor case

- Three scenarios: no backhaul, MW backhaul and fiber backhaul

![Graph showing power consumption vs. area throughput for different backhaul scenarios.](image)
Case study: HetNet indoor deployment

Step 1: Traffic forecast
- mobile subscribers
- penetration rate of tablets, smartphones, laptops...
- user types: heavy, ordinary
- active users at busy hours
- Population density
- Number of buildings
- User demand
- Traffic distribution

Step 2: Wireless Network Dimensioning
- femto offloading gain
- bandwidth
- macro capacity
- femto penetration rate
- BS power consumption
- Average traffic per BS
- Peak rate per BS
- Number of BSs, types

Step 3: Backhaul Network Dimensioning
- technology (fiber, MW, copper)
- topology
- switch capacity
- number of ports

Step 4: Assessment of total power consumption

Total Power Consumption = Wireless + Backhaul
HetNet indoor deployment parameters

- Area: 10 x 10 km² with 300,000 users
- 100,000 apartments and 10,000 buildings
- User density: $\rho = 3000$ user/km² i.e., average EU city [Earth project]
- Femto penetration rate ($\eta$) $\in$ (0.1, 0.6)
- Indoor users covered by femto BS, outdoor users by macro BS

<table>
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<th>Year</th>
<th>$h$</th>
<th>$s_{pc}/r_{pc}^{heavy}$</th>
<th>$s_{tablet}/r_{tablet}^{heavy}$</th>
<th>$s_{s.phone}/r_{s.phone}^{heavy}$</th>
<th>$R_{max} = \max_t(R(t))$</th>
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<td>10</td>
<td>0.1 / 56.25</td>
<td>0.03 / 28.1</td>
<td>0.3 / 7</td>
<td>2.6</td>
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<td>20</td>
<td>0.2 / 900</td>
<td>0.05 / 450</td>
<td>0.5 / 112.5</td>
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<td>0.3 / 2700</td>
<td>0.1 / 1350</td>
<td>0.6 / 337</td>
<td>474.3</td>
</tr>
</tbody>
</table>
Indoor deployment: backhaul architectures

- Femto BS will not drive the deployment of a completely independent backhaul infrastructure
- Rely on existing residential broadband access technologies (backhaul and user data share the access bandwidth)
- Considered BH options:
  - FTTN + VDSL
  - FTTB with PtP optical links
  - FTTH with passive optical networks (PON)
  - Microwave only

\[ P = \sum_{i=1}^{m} N_i P_i + P_{bh}, \]
BH with FTTN + VDSL

\[ P_{MBH}^{FTTN} = N_{femto} P_{modem} + N_{DSLAM} (P_{DSLAM} + 2P_{SFP}) + N_s^F P_s^F + 2N_{macro} P_{SFP} + N_{ul} P_{SFP} \]
BH with FTTB with PtP optical links

\[ P_{MBH}^{FTTB} = N_b(P_{GES} + 2P_{SFP}) + 2N_{macro}P_{SFP} + N_s^F P_s^F + N_{ut}P_{SFP+} \]
BH with FTTH using PON

\[ P_{MBH}^{FTTH} = (N_{femto} + N_{macro})P_{ONU} + N_{OLT}P_{OLT} + N_{ul}P_{SFP+} \]
BH with microwave only

Microwave Hub

SFP+

Metro Network

$P_{MBH}^{MW} = \sum_{j=1}^{N_b+N_{macro}+N_{hub}} P_j^{MW} + N_{GES}P_{GES} + N_{ul}P_{SFP+}$

$P_j^{MW} = \begin{cases} P_{low-c} & \text{if } N_{ant} = 1 \\ P_{high-c} + \frac{C_i}{C_{switch}}P_{SFP+} & \text{otherwise} \end{cases}$
Indoor case: total power consumption

- FTTN using VDSL
- FTTB using P2P optics
- FTTH using PON
- Microwave
Conclusions

- Presented two case studies assessing the impact of BH in HetNet deployments
- Power consumption of BH is important part of the total network power consumption
- It needs to be carefully included in any deployment strategy with objective of minimizing total network power consumption
- From a pure power consumption perspective a fiber based solution outperforms all the other options, but other factors of TCO shall also be included in future studies
References


• P. Monti, S. Tombaz, L. Wosinska, J. Zander, "Mobile Backhaul in Heterogeneous Network Deployments: Technology Options and Power Consumption", in Proc. of IEEE International Conference on Transparent Optical Networks (ICTON), July 2-6, Warwick, UK, 2012

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