Energy Saving in Fixed Wireless Broadband Networks

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Abstract. In this paper, we present a mathematical formulation for saving energy in fixed broadband wireless networks by selectively turning off idle communication devices in low-demand scenarios. This problem relies on a fixed-charge capacitated network design (FCCND), which is very hard to optimize. We then propose heuristic algorithms to produce feasible solutions in a short time.

1 Introduction

Fixed broadband wireless communications is a sector of the communication industry that holds great promise for delivering private high-speed data connections \cite{1}. Such network comprises remote locations, each of them served by a radio base station (RBS), connected by means of high-capacity microwave radio links. A bidirectional link connecting two RBSs requires a dedicated pair of outdoor units (ODUs), each one directly coupled to a high-directional antenna.

Commonly, in this context, the network is built in a robust fashion to guarantee fault protection and to support the extremely bursty traffic behaviors. As a drawback, since ODUs consume substantial power whenever the link is up, it brings forth important energy waste to provide extra resources which could be used only in critical situations. Therefore, the traffic fluctuation over the time offers an opportunity to energy savings by handling traffic efficiently and turning off devices used to keep microwave radio links whose capacities are underused.

In this work, we consider the problem of deciding both the network’s configuration and flows that minimize the total energy expenditure. Particularly, by configuration, we mean the choice of which communication devices we need to keep on to successfully meet the traffic requirements. This problem relies on a fixed-charge capacitated network design (FCCND), which is very hard to optimize \cite{6}. Among others, \cite{4} and \cite{7} tackled similar problems on different networks. We present an exact formulation for this problem and propose heuristics that may be employed to produce good feasible solutions in a short time.

2 Problem Modeling and Linear Formulation

The network topology is modeled by a digraph \( H = (V, E) \) where every node \( v \in V \) represents a base station and every arc \( vw \in E \) represents a radio link. Every link has a

\textsuperscript{*} This work has been partially supported by project APRF RAISOM (PACA & FEDER), ANR DIMAGREEN, and Villum Kann Rasmussen foundation.
capacity $c_{vw}$ and can be either active (while consuming energy) or not. Traffic demands are defined by $|D|$ pairs $(s^d, t^d)$, with $s^d, t^d \in V$ and by an average volume per demand $h^d$. We assume that $H$ is symmetric since in the type of studied networks, radio links are usually symmetric. This implies that for every node $v \in V$, the entering neighborhood is the same as the leaving neighborhood, i.e. $\delta^+(v) = \delta^-(v) = \delta(v)$. Also the cost of an active link is constant and equal to $CL$ (as shown in [5]). Another assumption that we consider in this work, and which is not always true, is the possibility of routing the traffic of the same demand $d$ through different paths from $s^d$ to $t^d$ (multi-routing).

The problem can be formulated as a mixed integer program (MIP). We define two types of variables: to represent the state of link $vw$ we consider a binary decision variable, being equal to 1 if the link is active and 0 otherwise. Since symmetric links must be in the same state, and in order to reduce the total number of binary variables, we use a single variable $u_{vw}$ with $v < w$ (assuming some ordering of the nodes) for the pair of symmetric links $vw$ and $wv$. We also employ a variable $x_{vw}^d$ to indicate the volume fraction of the demand $d$ which is routed through the link $vw$. In the MIP formulation, Eq. (1) is the objective function, Eq. (2) are the capacity constraints on the links, and Eq. (3) are the flow conservation constraints.

\[
\begin{align*}
\min \sum_{vw \in E} CL \cdot u_{vw} \\
\text{s.t.} \sum_{d=1}^{D} x_{vw}^d &\leq c_{vw} u_{vw} & \forall vw \in E \\
\sum_{w \in \delta(v)} x_{wv}^d - \sum_{w \in \delta(v)} x_{vw}^d &= \begin{cases} 
-h^d, & \text{if } v = s^d, \\
h^d, & \text{if } v = t^d, \\
0, & \text{otherwise} 
\end{cases} & \forall v \in V, \forall d = 1, \ldots, |D| \\
x_{vw}^d &\in [0, h^d] & \forall vw \in E, \forall d = 1, \ldots, |D| \\
u_{vw} &\in \{0, 1\} & \forall vw \in E
\end{align*}
\]

3 Hybrid Algorithm

The model cited in the previous section is a mixed integer linear program. Even though it can be handled by a solver like “CPLEX”, this may take a very long time on relatively large networks (containing more than a hundred nodes). The number of variables and constraints can be huge and not even fit in memory. For such networks, we built a hybrid solution by combining a heuristic based on simulated annealing and a linear program with real variables (Multi Commodity Flow - MCF). The former would be the master and on every iteration it chooses the links to turn on/off. The latter, which is the slave, will only find out whether there is a feasible solution with this configuration or not (see Figure [1]). Actually the linear program will have the same formulation except that the link state variables $u_{vw}$ will now be constant. Therefore there will be no more integer variables in the program, which makes it faster to solve.

At each iteration of the simulated annealing process, a new network configuration is generated from the current solution by switching the state (Up Down or Down Up)