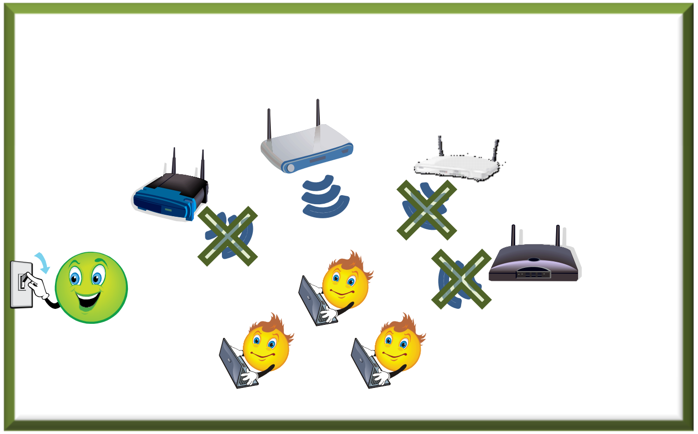
A Simple Analytical Model for the Energy-Efficient Activation of Access Points in Dense WLANs



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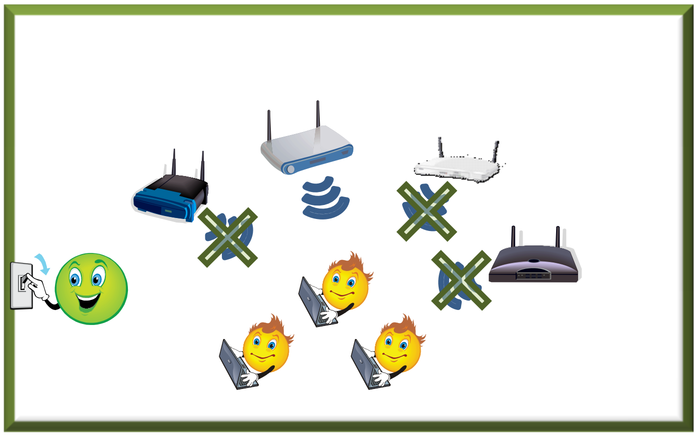

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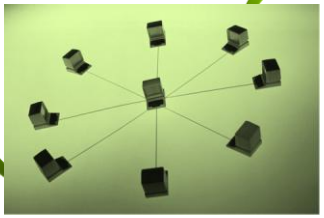
Why energy efficiency?

- Energy is a *huge* cost, increasing rapidly
- Rules and laws are going to enforce energy consumption reduction
- New sensitivity towards environmental concerns will drive the market

- Reduce energy wastage

- Improve energy efficiency



Why Green Networking?

ICT as a part of the solution…

"ICT alone is responsible for a percentage which varies widely from 2% to 10% of the *world* power consumption."

"The ICT sector produces some 2 to 3% of total emissions of greenhouse gases."

At the same time, **ICTs can significantly help reduce climate change by:**

- ***moving bits instead of atoms*** (remote collaboration, e-commerce, intelligent transport systems, electronic billing);
- allowing the implementation of **smart grids**;
- promoting the development of **energy efficient** devices, applications and **networks**;

Motivations

- The number of **APs** (Access Points) in **dense WLANs** (Wireless LANs) is **huge** (order of thousands).

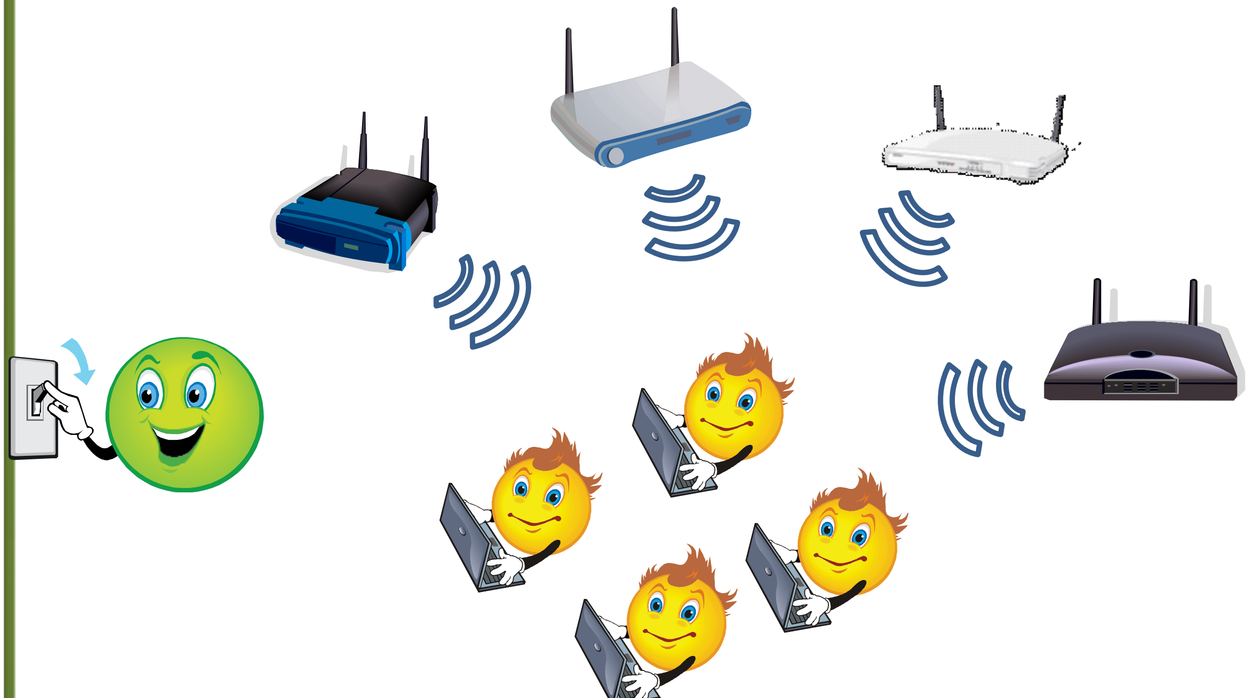
- The **energy** consumed by such a huge number of APs is largely **wasted** in **low traffic** periods.

- Every AP consumes about 10 W in the *ON* mode, almost 90 kWh a year:
  - For a **WLAN with 10,000 APs** this means almost 1 GWh a **year**; with a cost of the order of **150,000 €.**

- Only a **minimal** amount of **energy** is needed by the **APs** in the ***OFF* mode**.

Our Goal: energy efficiency

Activation of network resources on demand: turn off APs during low traffic periods



Related Work

Jardosh, K. Papagiannaki, E. Belding, K. Almeroth, G. Iannaccone, and B. Vinnakota, *"Green WLANs: On-Demand WLAN Infrastructure"*, Mobile Networks and Applications (MONET), special issue on Recent Advances in WLANs, April 2009.

They propose a resource-on-demand (**RoD**) policy **to dynamically power on and off** WLAN **APs** based on the volume and the location of user **demand**.

They show **experimentally** that huge energy savings (up to 54%) are possible in the examined configurations.

In our work, we use the ***cluster model*** of Jardosh *et al.*, in which **a cluster is formed by a number of APs (8 in our case) which are in close proximity of each other, so that the coverage they offer is equivalent.**

Three Laws

The 3 goals of our RoD policies:

1) **The WLAN coverage must not be reduced**

2) **The QoS offered to end users must not be degraded**

3) **The WLAN operations must be stable**

The System (I)

We develop a **first** simple **analytical model** to test the effectiveness of policies that activate APs in dense WLANs according to the user demands.

We propose two policies for the APs switch-off and switch-on:

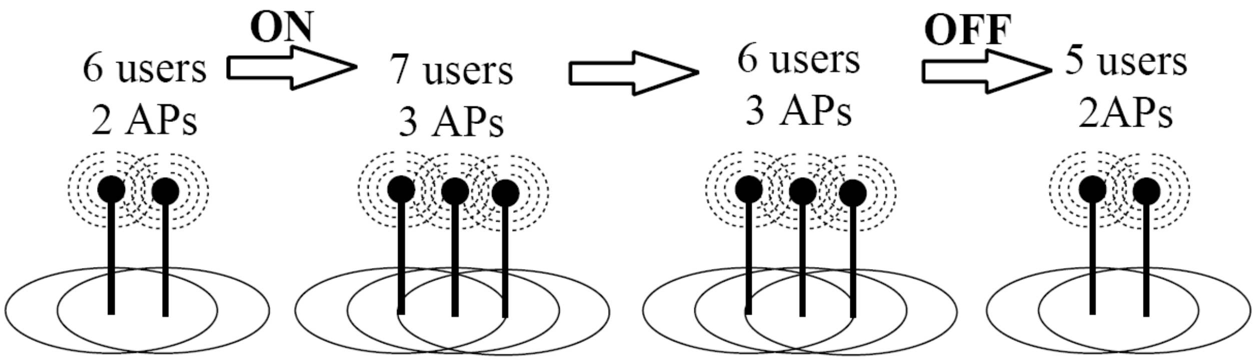
1) The ***association-based*** policy is based on the number of users **associated** with APs in the cluster.
   - Denote with *M* the maximum number of users associated to an AP, and with $\boldsymbol{T_h} \leq \boldsymbol{M}$ a threshold.
   - When the number of users associated with APs in the cluster is above $\boldsymbol{kT_h}$, the number of active APs must be *k+1*.

2) The ***traffic-based*** policy is based on the users are not only associated, but are in addition **generating traffic**.
   - When the number of traffic-generating users associated with APs in the cluster is above kC_h, the number of APs must be at least *k+1*.

The System (II)

To avoid frequent AP switch-off and switch-on and frequent re-associations of users, in the switch-off procedure, we use a **hysteresis** of amplitude: T_l (C_l) for the association (traffic) policy.

Example of a hysteresis cycle with T_h =3 users per AP, and T_l =1 user:



The System (III)

Input model parameters:

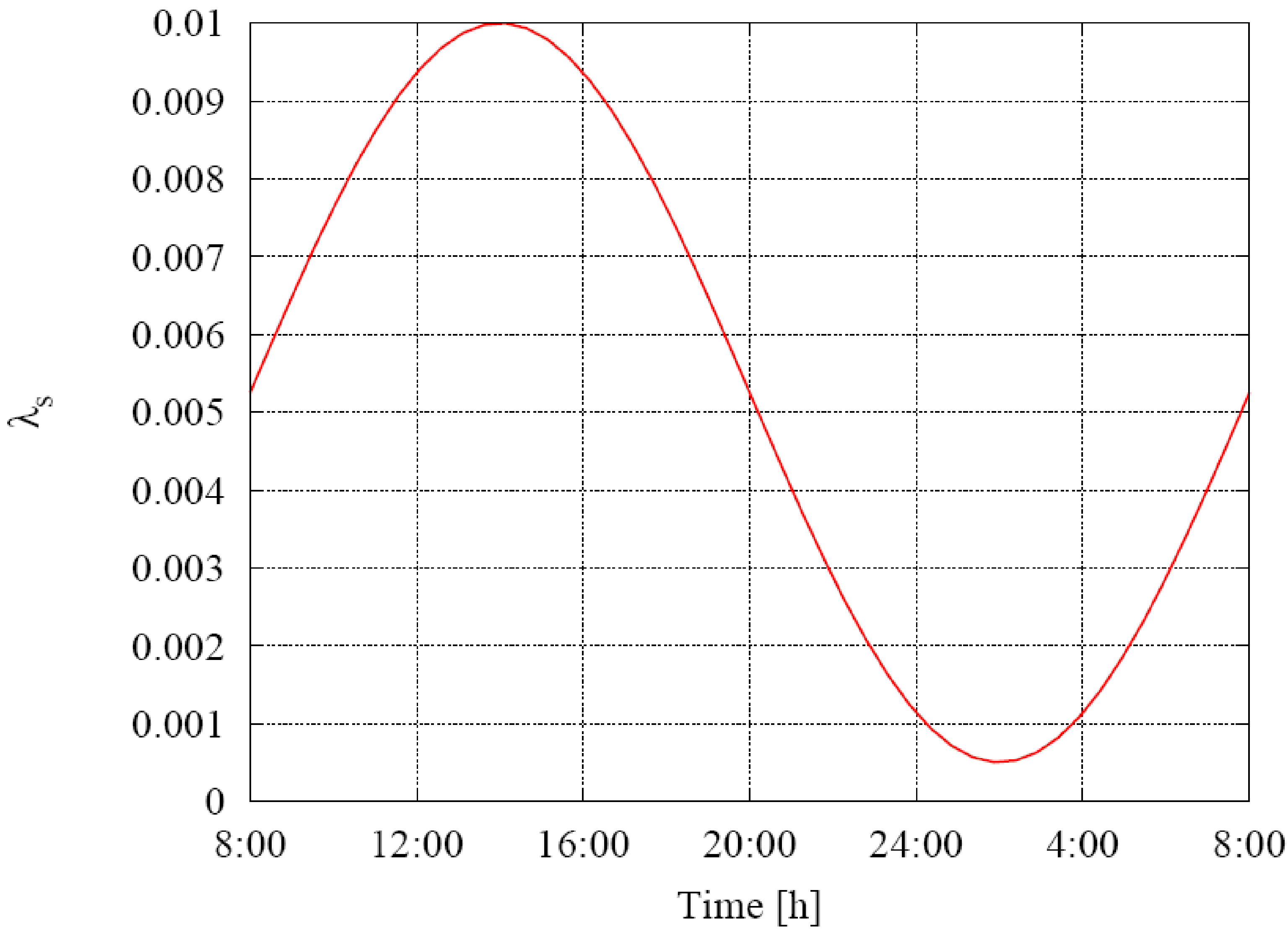
- Users associate according to a Poisson process with rate λ_s ;
- Users leave the cluster after an exponentially distributed time with mean $1/\mu_s$;
- Associated users can be *idle*, when they do not generate traffic, or *active*, when they are generating traffic
  - An idle user becomes active after a time whose pdf is $exp(\lambda_c)$;
  - The amount of traffic generated by active user follows an exponential pdf with mean $1/\mu_c$.

Performance indices

To compare the performance of our RoD policies, we develop a continuous-time Markov chain (CTMC) model of a cluster of APs and we evaluate the following parameters:

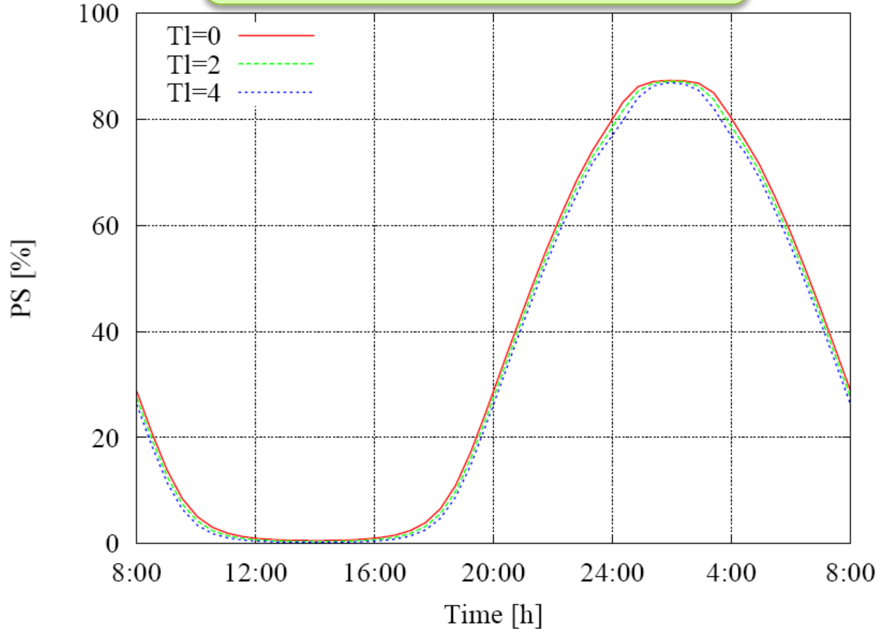
- The ***switch-off rate R***, i.e. the average number of times an AP is switched on (or off) in the time unit;
- The ***average bandwidth per connection B***;
- The ***power consumption*** P_A of the always-on policy;
- The ***power consumption P*** of our RoD policies;
- The ***percentage power saving PS*** as: $PS = 100\frac{P_A - P}{P_A}$

User association rate λ_s

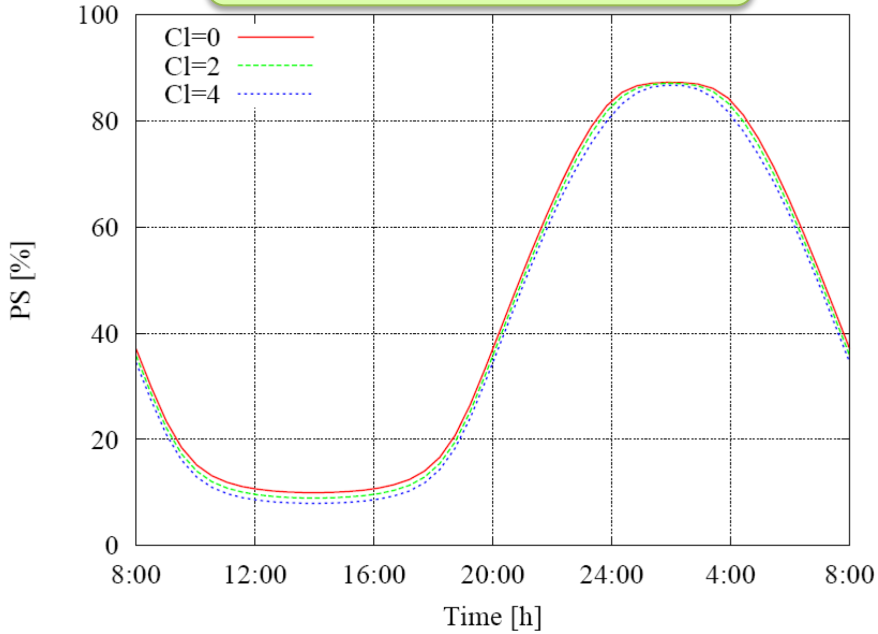


RoD policies comparison: Power Saving

Association-based policy



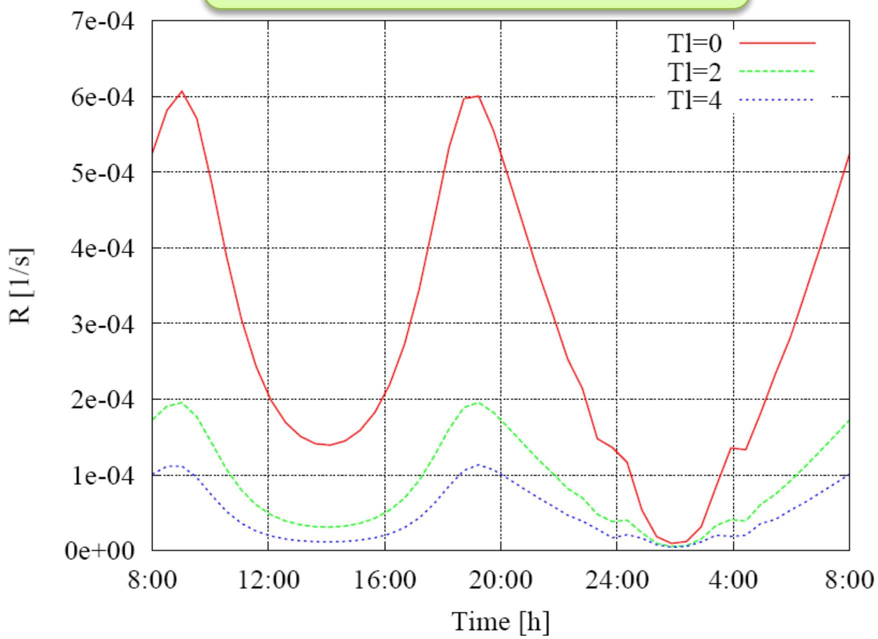
Traffic-based policy



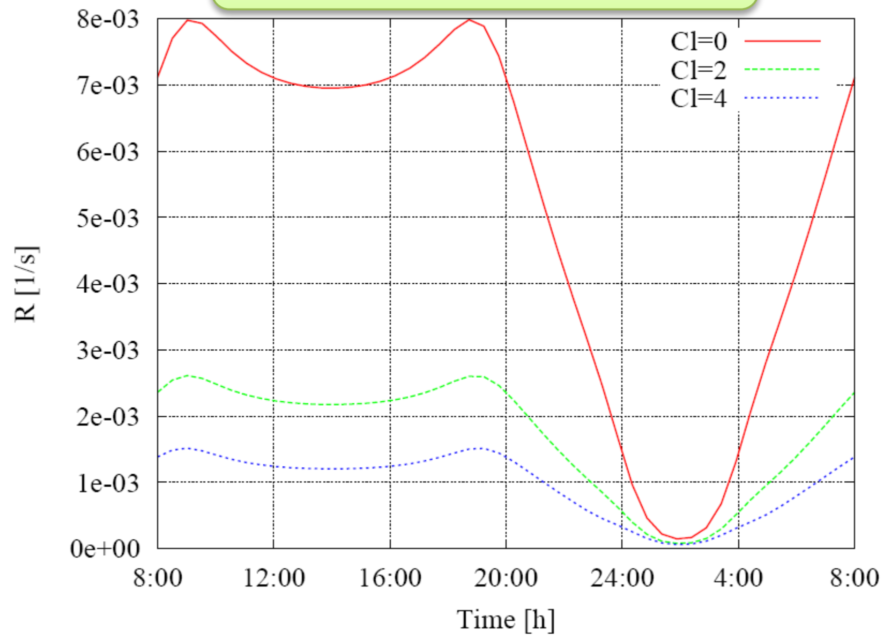
$T_h = 10$ $C_h = 4$ $1/\mu_s = 10000$ s $1/\mu_c = 200$ s $1/\lambda_c = 1250$ s

RoD policies comparison: AP switch-off rate

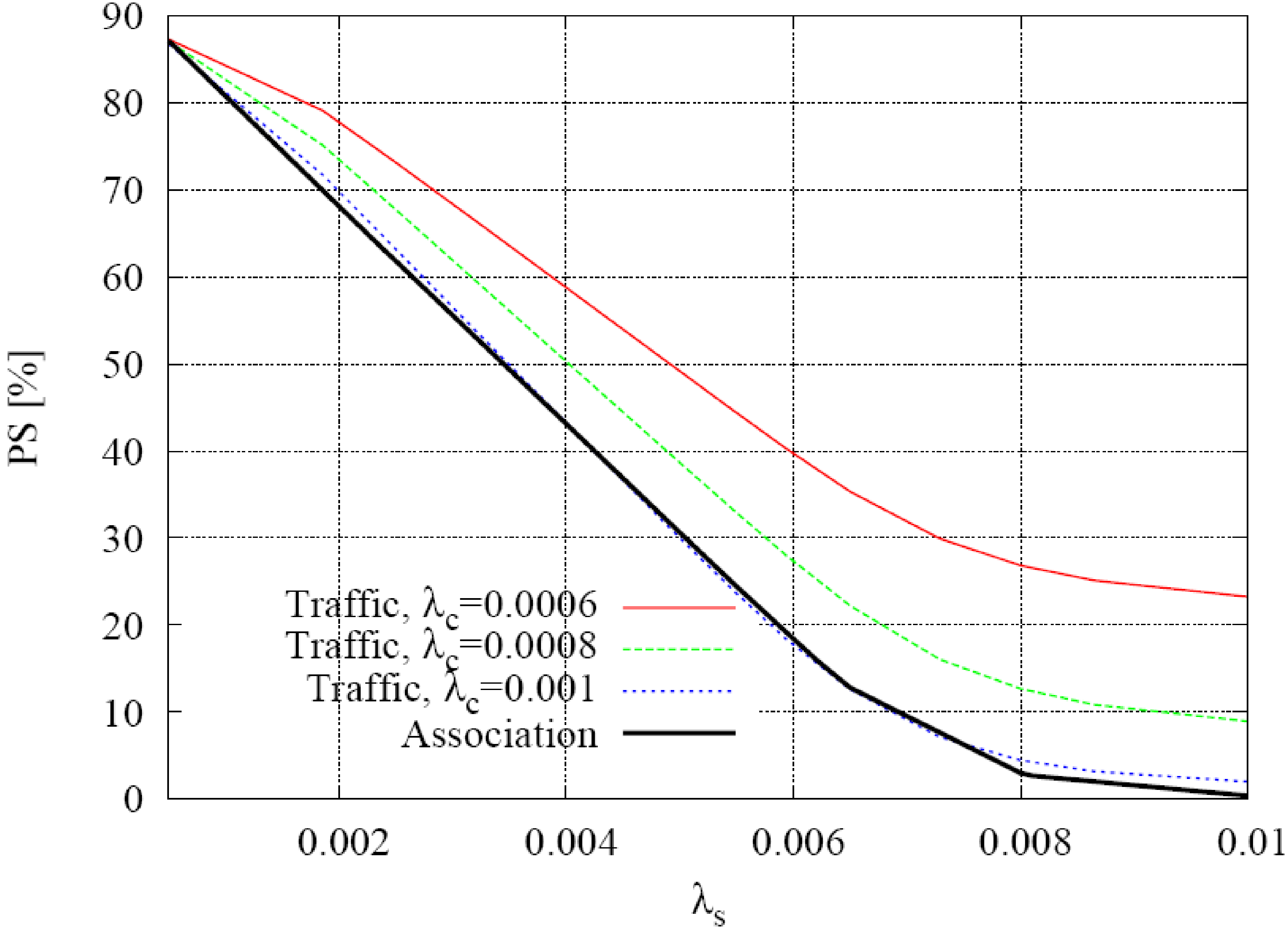
Association-based policy



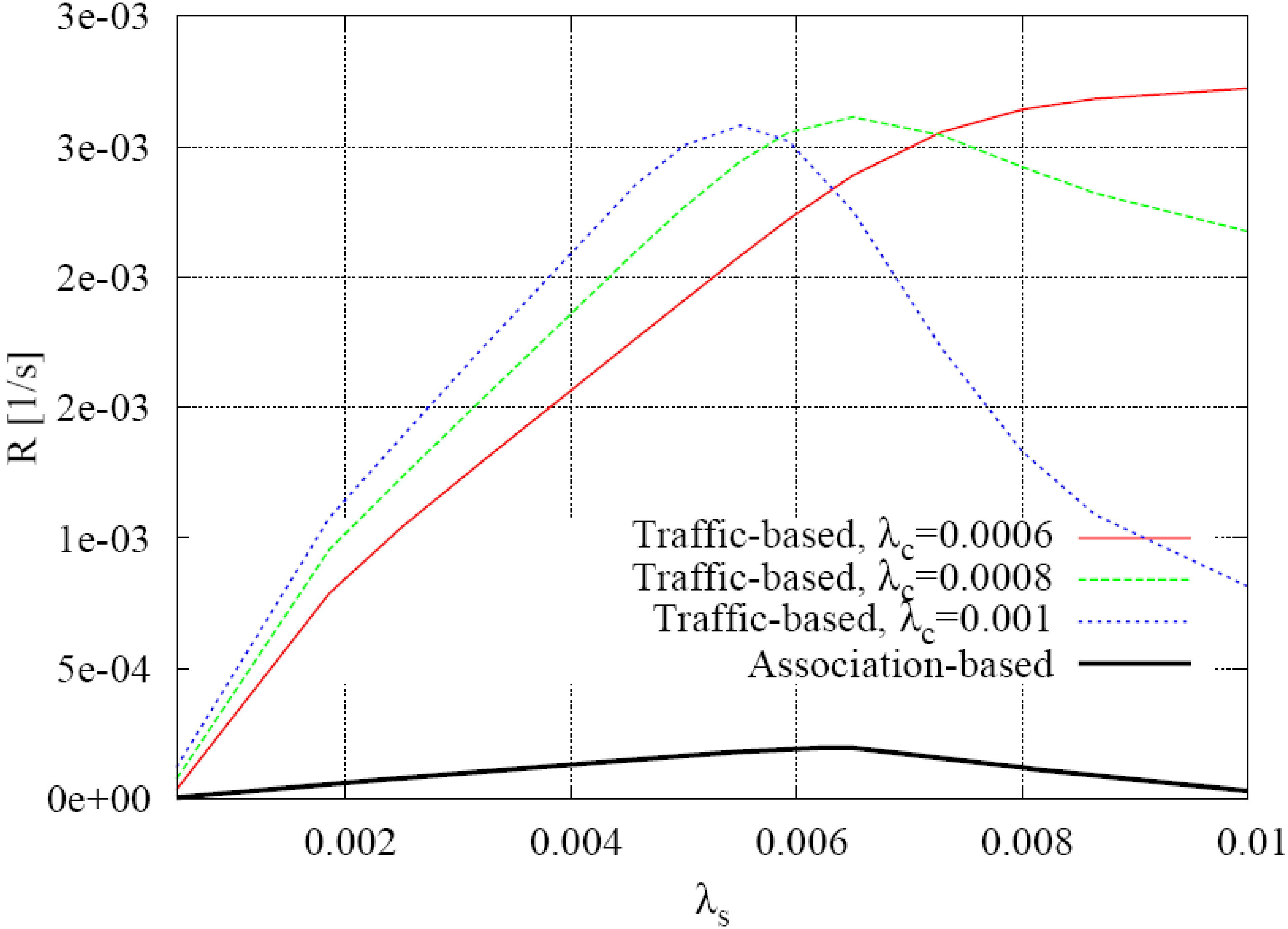
Traffic-based policy



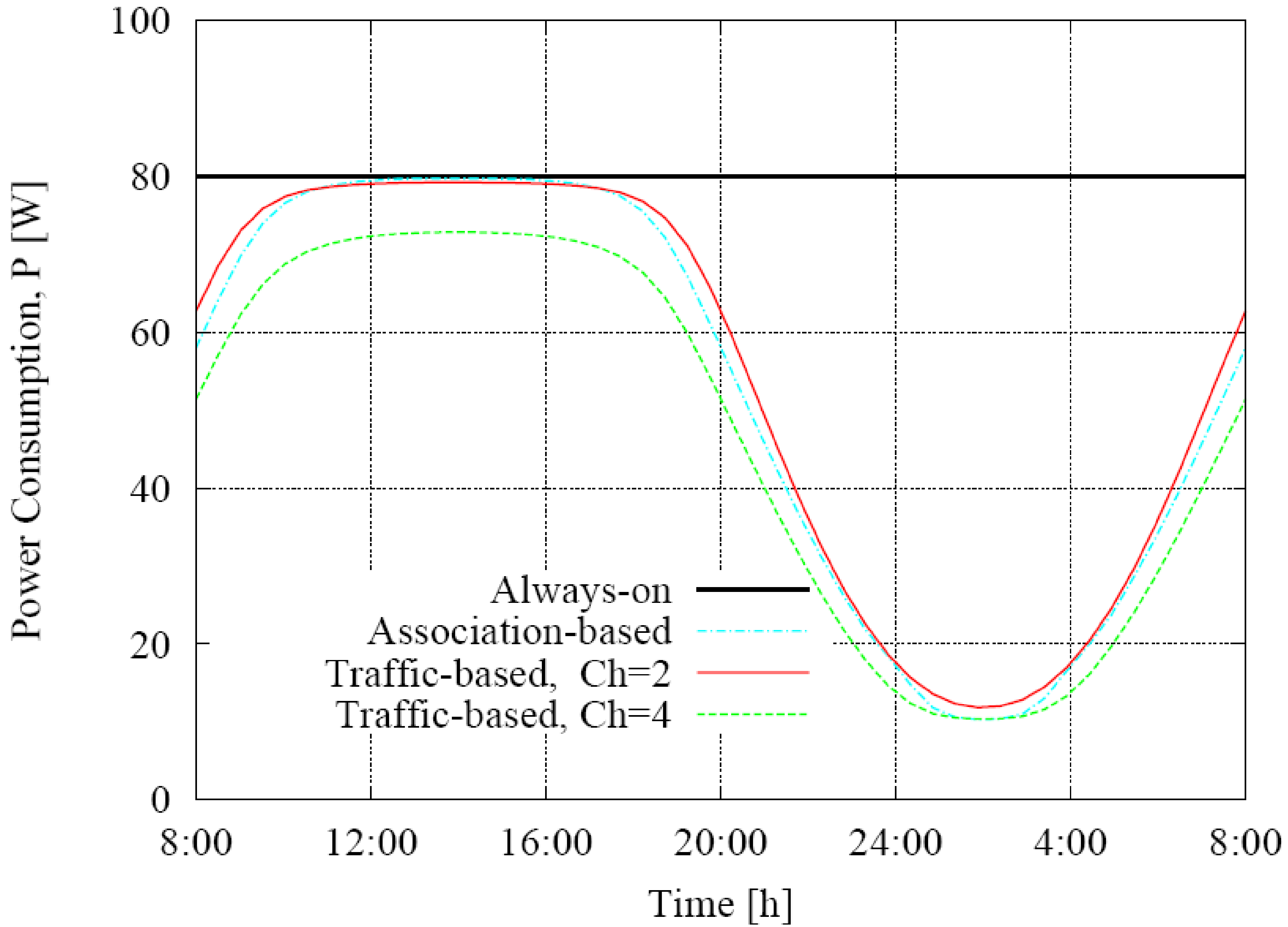
Power saving vs association rate (Tl=2, Cl=2)



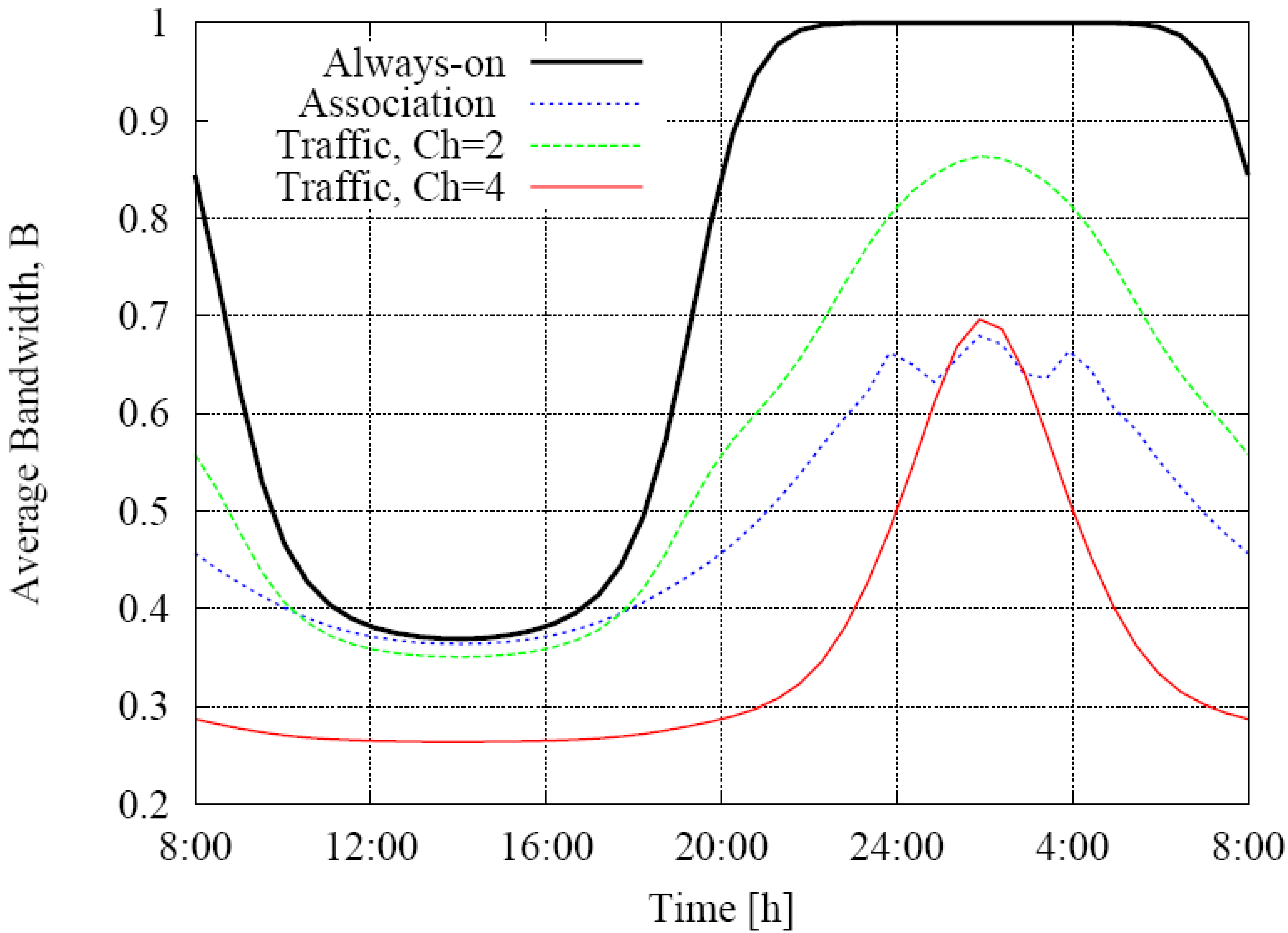
Switch-off rate vs association rate (Tl=2, Cl=2)



Power consumption



Average bandwidth per active user



Summary of results

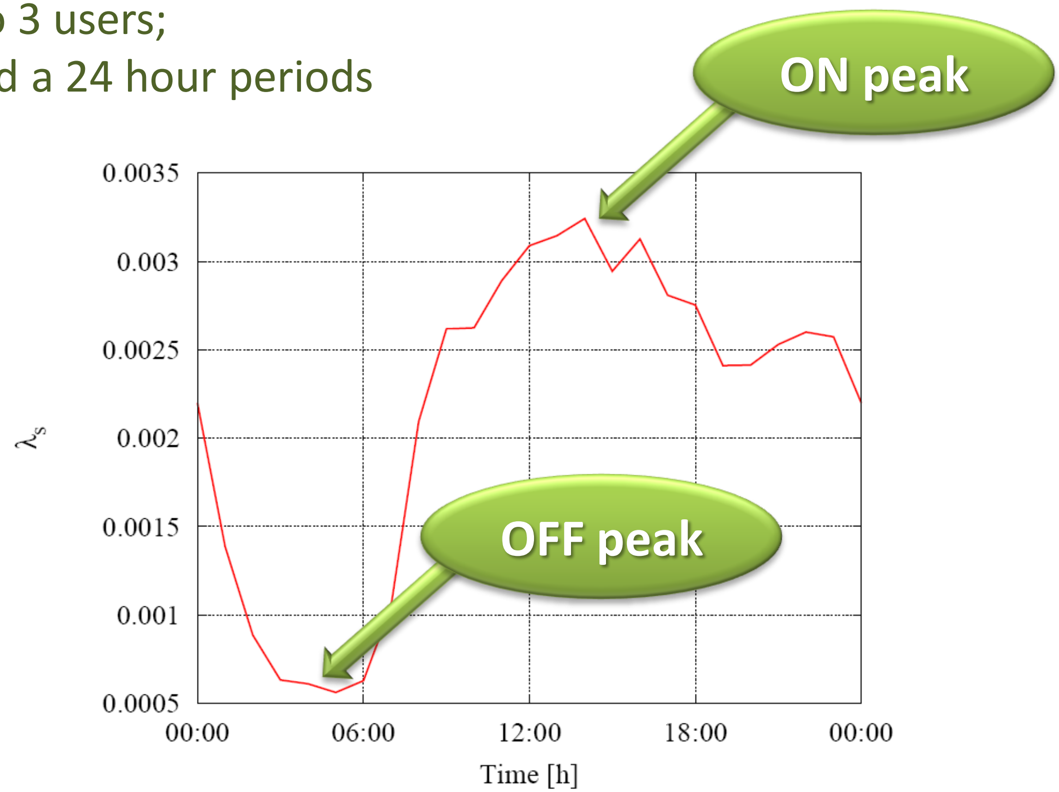
Policy	[illegible]ar]	ES [%]
[illegible]	[illegible]	36.2 35.3 34.4
[illegible]	[illegible]	43.2 42.2 40.9

Savings largely over **30%** in all cases

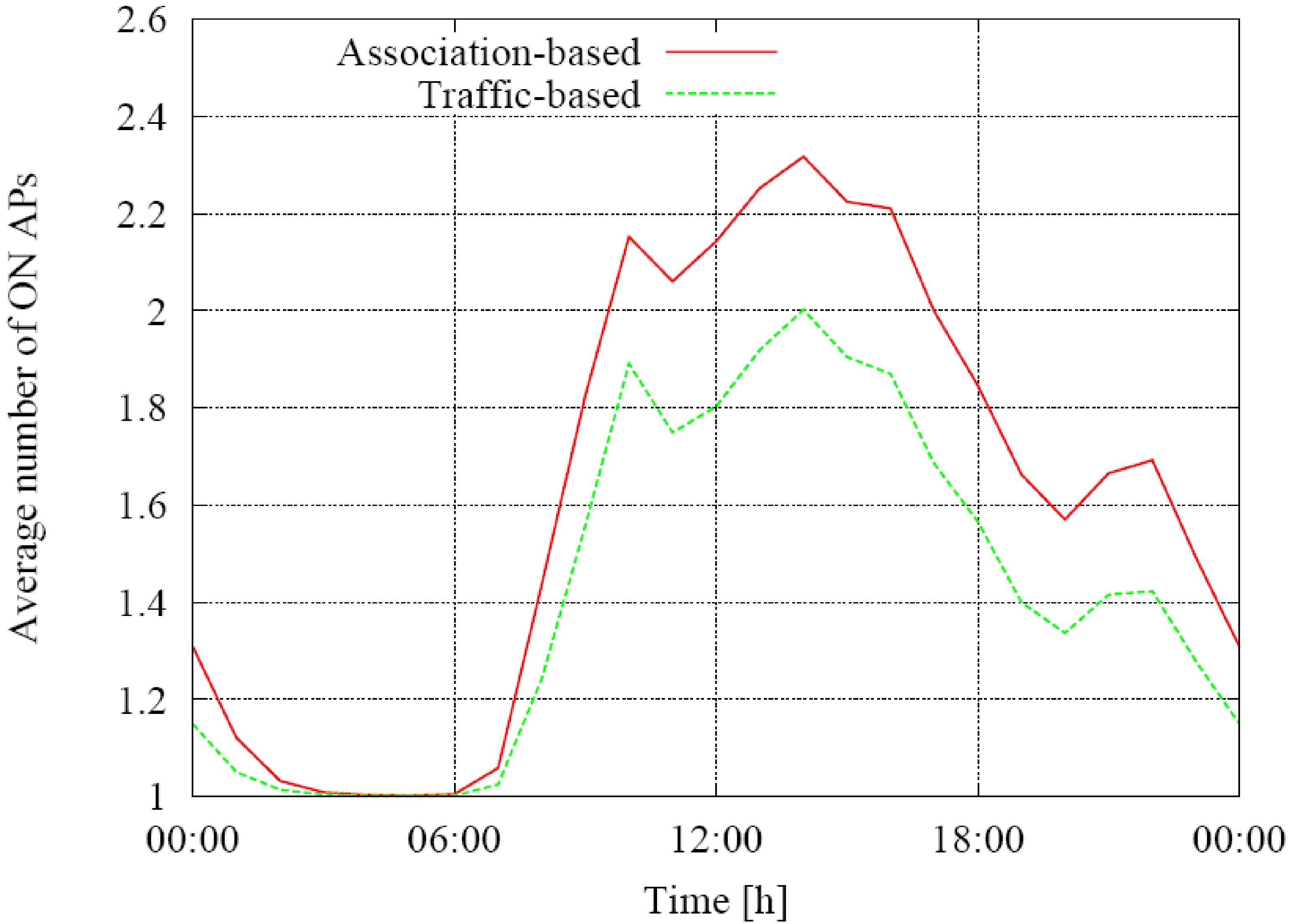
Model validation: a case study

We validate our analytical model by comparing its prediction against the experimental results of Jardosh *et al.:*

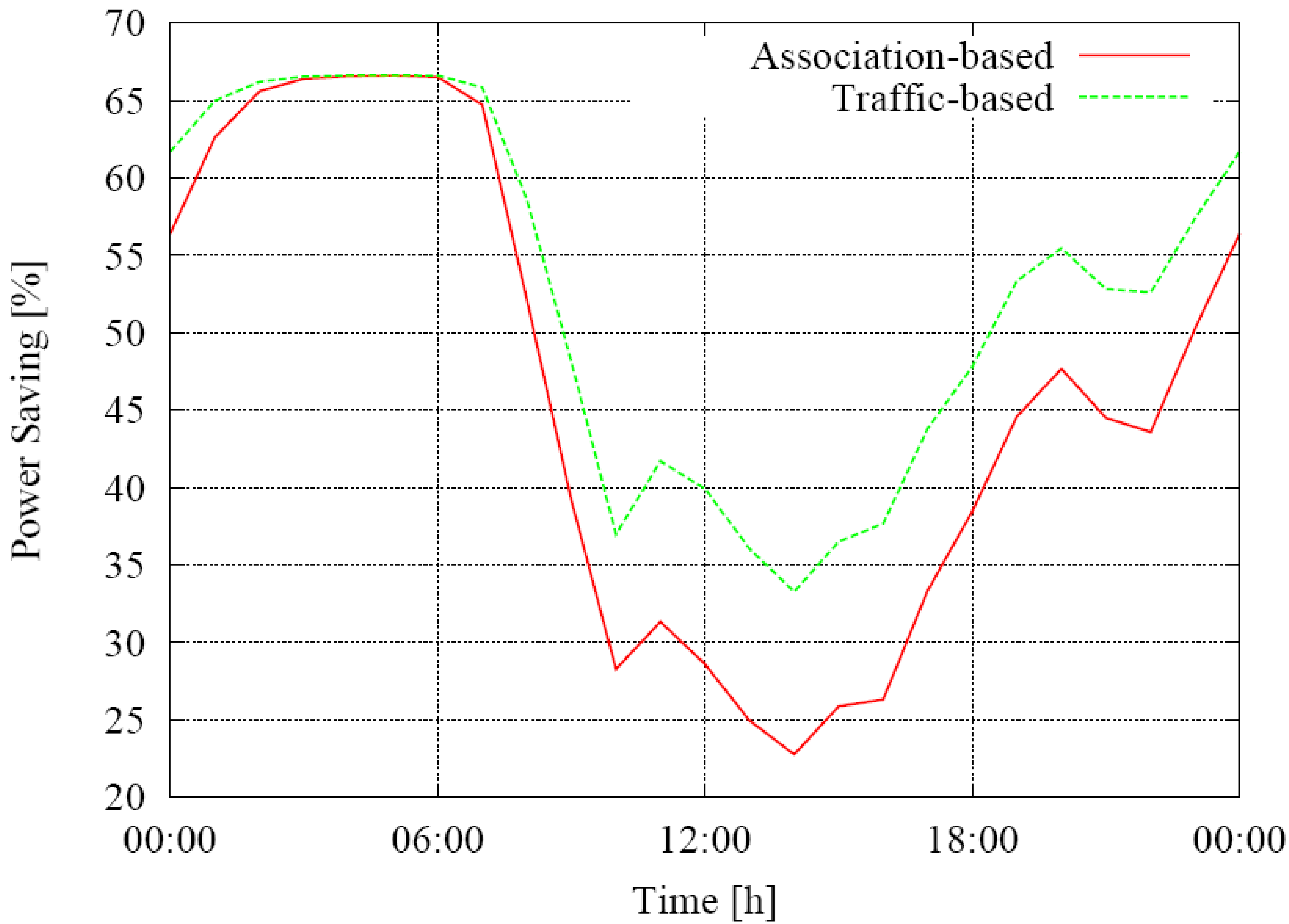
- we consider as input the same traces (CRAWDAD trace set);
- as in [Jardosh *et al.*], we studied a small cluster of 3 APs, each capable of serving up to 3 users;
- we analyzed a 24 hour periods



Case study: On APs



Case study: Power saving



Conclusion and Future Works

- First analytical model to test the effectiveness of policies that activate APs in dense WLANs according to user demands;
- Potential energy savings up to 87% (7/8) during low traffic periods.

- Improve the analytical model to better describe real WLANs;
- Define more elaborate policies to achieve large energy savings and good QoS.

Thanks

- THANKS

- QUESTIONS?