## Toward sustainable networks

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## Next GWiN September 2018



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#### Is sustainability an issue?

- According to recent estimates, ICT industry
  - generates about 3% of emissions today
  - might generate up to 14% emissions by 2040

*Source:* Lotfi Belkhir, Ahmed Elmeligi, "Assessing ICT global emissions footprint: Trends to 2040 & recommendations", Elsevier Journal of Cleaner Production 177 (2018) 448-463

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ICT Global Carbon Footprint relative to Total WW Footprint

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#### Where is the forecast coming from?

- The expected growth of electricity demand and hence emissions is due to the data tsunami
- Traffic increase is due to a number of reasons
  - high-rate multimedia applications

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- traffic generated by several connected vehicles and machines
- robots and digitalized systems producing huge amounts of data
- huge amounts of data to be stored in data centers
- more people connected in developing countries



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#### Data tsunami: traffic growth

- IP traffic will triple in 5 years!
- An increasing portion is mobile



#### Source: Cisco VNI, 2017



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#### Data tsunami: high-rate services

The popularity of high-rate services is increasing



Source: Cisco VNI, 2017

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#### Data tsunami: growth of IoT devices

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#### Data tsunami: traffic growth everywhere

CAGR between 21% and 50%



Source: Cisco VNI, 2017



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#### Not only a matter of consumption

- Consumption is only one side of the story
- Sustainability issues have to be evaluated by considering how electricity is generated (carbon footprint)



#### What do these data say?

- There is and will be a significant increase of ICT technologies, everywhere, with more demanding services
- ICT energy consumption grows at a faster pace than other sectors: the portion of electricity usage for ICT grows
- Electricity generation is still mainly based on fossil fuel, there is a threat to climate and environment
- There is an issue of ICT sustainability

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Make ICT more sustainable: consume less, consume better



#### What do these data say?

- Energy consumption reduction alone is not enough
- Sustainability calls for new energy generation principles: need to use renewable energy sources but they are
  - Intermittent
  - Difficult to predict
- ICT services
  - Require reliability and continuity of power supply
  - Tend to be non-elastic in the time scale of energy generation
- Power supply and service provisioning must be considered jointly
  - Power supply  $\rightarrow$  tailored for service
  - Service provisioning  $\rightarrow$  aware of power supply





Source: The Zettabyte Era, Cisco white paper, June 2017

- Focus shift towards the edge of the network carrying
  - connectivity
  - computing and storage capacity

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Need for resource on demand approaches

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#### Green mobile networks



#### Joint work with M. Ajmone Marsan, D. Renga, G. Vallero



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#### Energy and resource management





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#### Energy and resource management





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#### Energy and resource management

#### **Objectives**

- minimizing operational costs (OPEX)
- guaranteeing good QoS
- providing service continuity
- preventing power outages
- responding to Smart Grid requests



Need to take decisions on energy to use

resource to allocate

Need to know (predict)

- generated energy
- traffic demand

ML approaches for prediction



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## Methodology





### Methodology



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#### Scenario

From the real data of an Italian operator, consider the following areas of Milan:

- 1. Residential
- 2. Business
- 3. Politecnico di Milano (campus)
- 4. Duomo (turistic)
- 5. Industrial
- 6. FS (Train station)
- 7. San Siro (stadium)
- 8. Rho Fiere (exhibitions)
- 2 months of data
- 1.5 month of training
- 14 days of operation



- PV panel
- 10 kWp of capacity per cluster
- Data from PVWatt (by NREL)



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## Comparison among ML algorithms





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## Comparison among ML algorithms



#### **Traffic prediction**

ANRME: Average (over the BSs) normalized root mean square error (over the predictions)



With the Baseline: Big error but little impact on QoS



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#### **Traffic prediction**

San Siro

Train

Station

Industrial

Ref Scen.

Ideal

2ANNs

1ANN

Rho Fiere

Error in periods that do not impact on BS operations and related decisions → predictions must be evaluated based on their impact on decisions





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needed to automatically adapt to the area characteristics

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2ANNs

1ANN

48ANNs

LSTMC

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**BaselineANN** 

## Conclusions

- ICT sustainability is a key challenge that requires the adoption of renewable energy sources
- Joint network and energy management strategies are needed to
  - Exploit at best the potentiality of resource on demand for consumption reduction
  - Effectively use renewable energy sources
- ML algorithms for predicting energy production and demand for services are effective
  - adapt to the characteristics of the various areas
  - adapt to the possible slow variations due to urban environment transformations



# Thanks!



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