Machine Learning and Networked Intelligence

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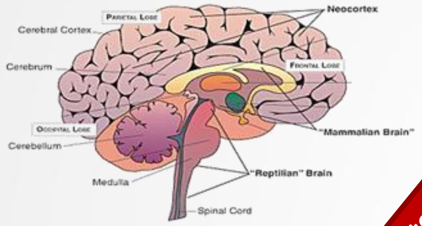
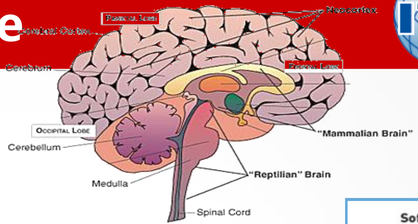
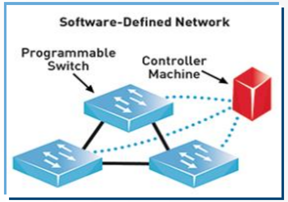
Evolution of Network Control Mode



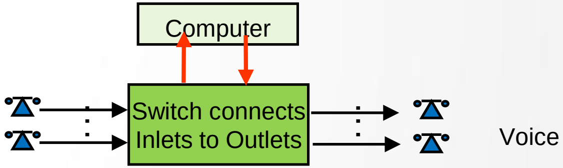
Increasing automation, complexity and intelligentization



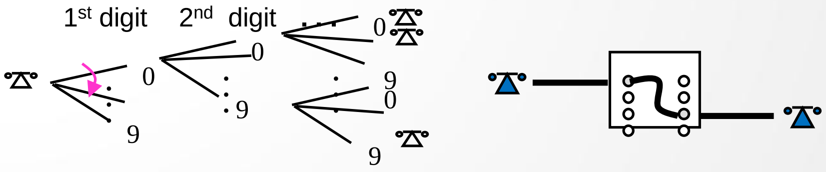
- Intelligent Control



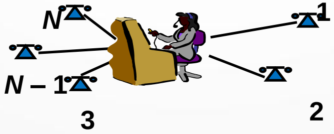
- Softwarization Control
- Stored Program Control



- Wired Logic Control



- Manual Exchange



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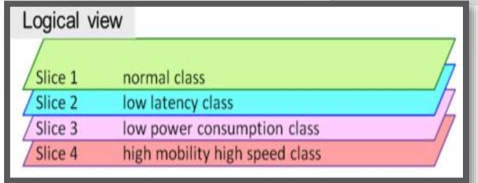
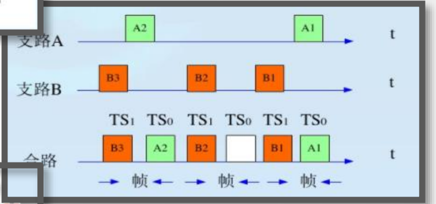
The Evolution of Network Resource Occupation Form

- Network Slice

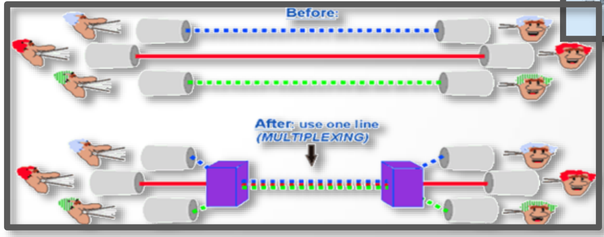


- Storage Capacity (Containers)
- Computing Power

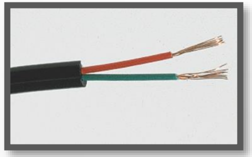
- Bandwidth (Statistical Multiplexing, Virtual Links)



- Time Slot (Multiplexing)



- Wired Logic Control
- Line (One To One)
- Manual Exchange



Increasing utilization, capacity, flexibility

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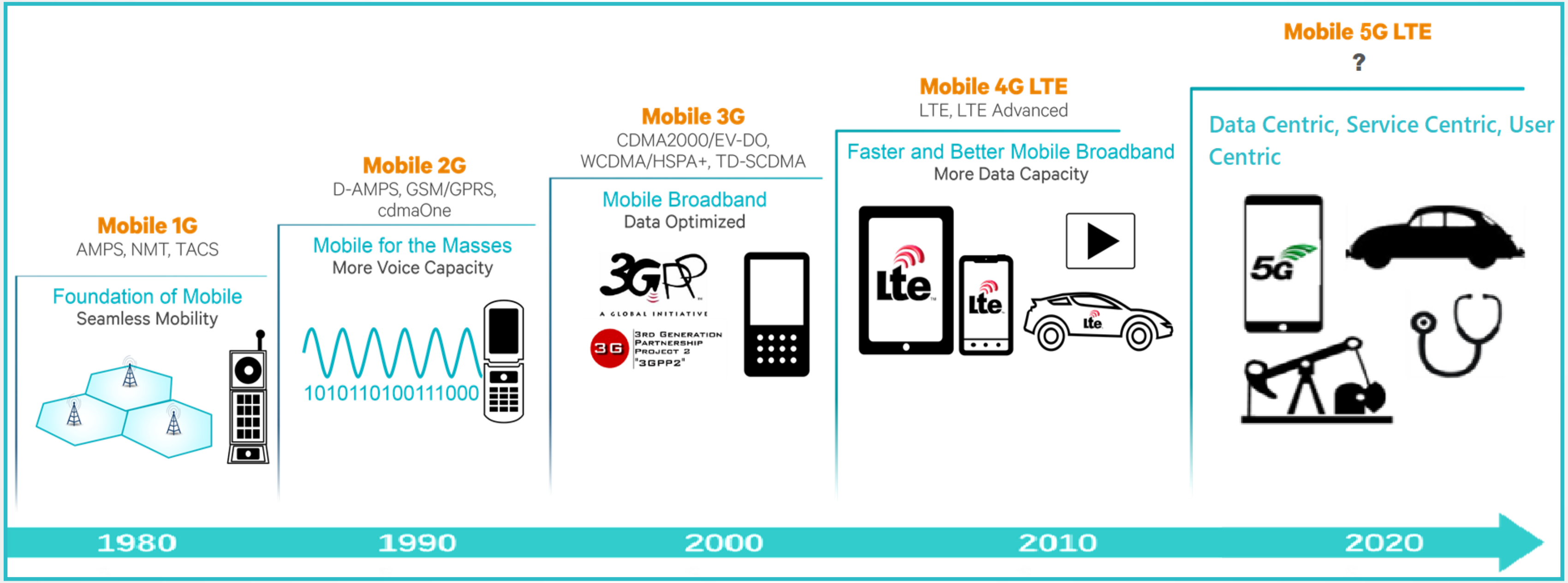
Evolution of Communication

Demands of the users will be the focus of the future network.



Who Use the Telecomm. Now and Future?

Category and quantity of the UEs is changing

IoT: Experts estimate that the IoT will consist of about 30 billion objects by 2020. It is also estimated that the global market value of IoT will reach $7.1 trillion by 2020.

5G: As of 2017, development of 5G is being led by several companies, including Samsung, Intel, Qualcomm, Nokia, Huawei, Ericsson, ZTE and others.

Demand of the enterprise

The promotion of the multimedia service

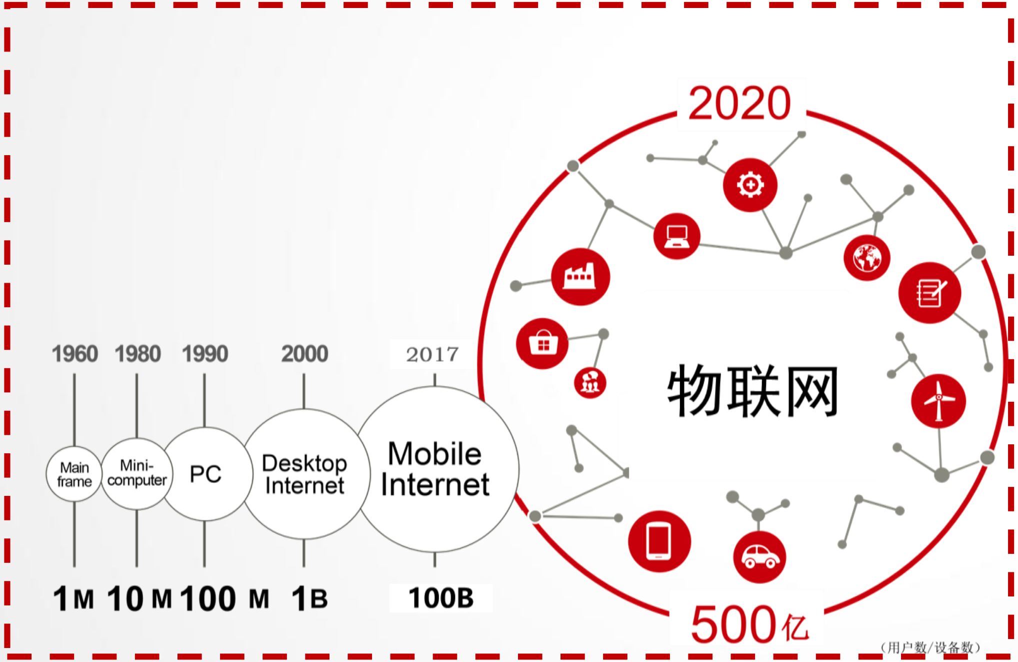
During the are of the Web 2.0, users are not only the producers, but also the consumers of the information.

Demand of user experiment

Challenges

- Dynamic services
- Dynamic users
- Dynamic terminals
- Dynamic traffic

IOT , Now and Future?



Challenges

Dynamic services

Dynamic users

Dynamic terminals

Dynamic traffic

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How the Telecom Networking?

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- Distribute the network resource based on need
- The classification and prediction of network traffic
- The security of the network
- The detection and recovery of the network failure

CHINA TELECOM

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让 一 切 自 由 联 通

中国移动通信 CHINA MOBILE
移 动 通 信 专 家

Dynamic network

- Dynamic and shared resources
- Adaptive functions
- Flexible network architecture
- Loosely coupling system

Challenges and opportunities

- Network reconfiguration
- Customized service
- Personalized service
- Cost reduction

Current Internet & mobile communications industry

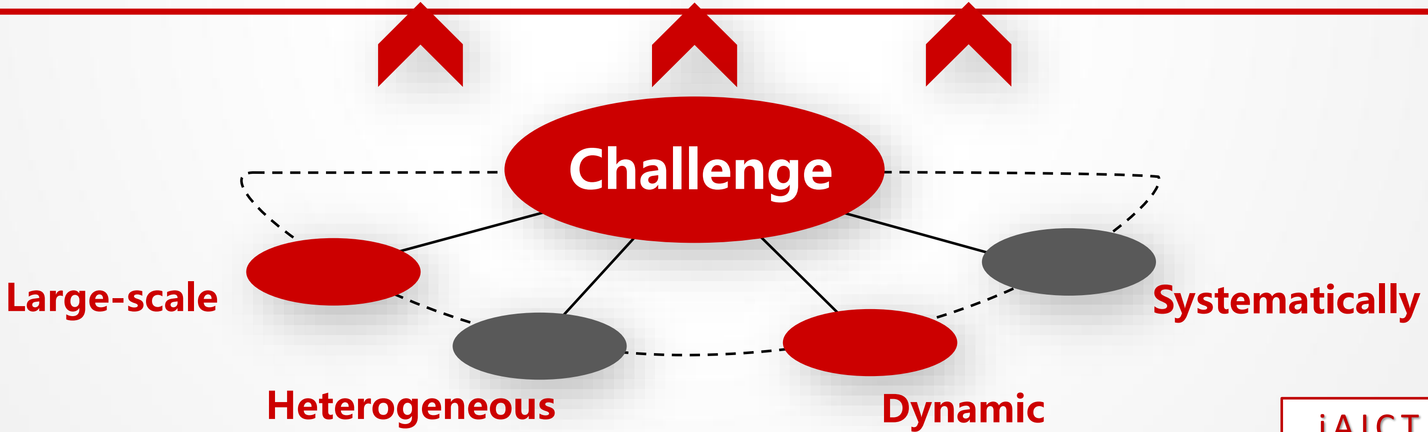
Challenges

Grown substantially larger as greater switching capacities are introduced in the Internet core and more, bigger routers with more/faster radio links are deployed in the wireless enterprise backbone networks.

Such complex network systems confront a myriad of challenges:

- Management
- Maintenance
- Awareness
- Network traffic optimization
- Security

……



What about the Networked Intelligence ?

Intelligent Algorithm

Autonomous learning
Autonomous analysis
Autonomous making decision
Autonomous execution
Autonomous network

Big Data

Massive network data
Cloud computing

"Brain" of the network

Network Architecture

SDN
NFV

Context-Aware

Aware and predict in real time
Pervasive Computing

Network Infrastructure

IoT
5G

SDN in Networked Intelligence

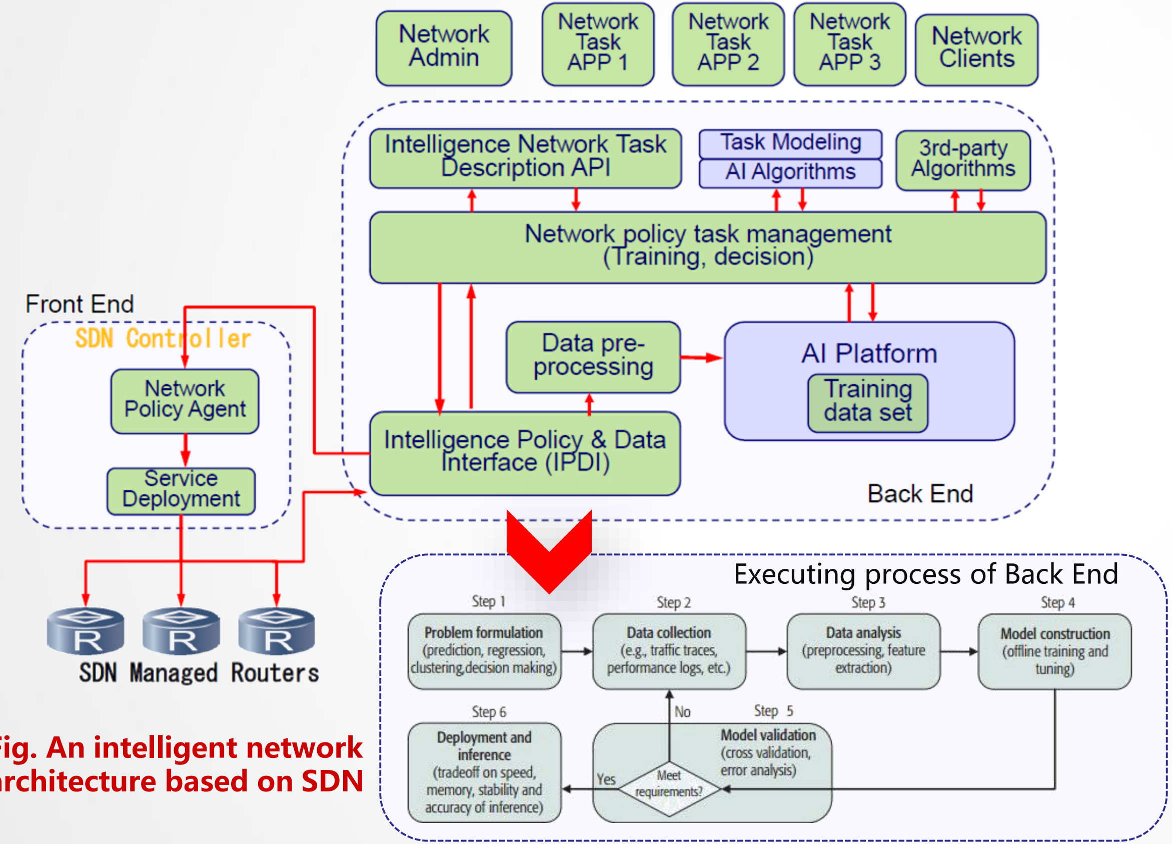


Fig. An intelligent network architecture based on SDN

Capability of SDN

NBI:

abstract description for the application requirements, deriving the forwarding table

SBI:

using YANG, or OpenFlow to configure the network forwarding table

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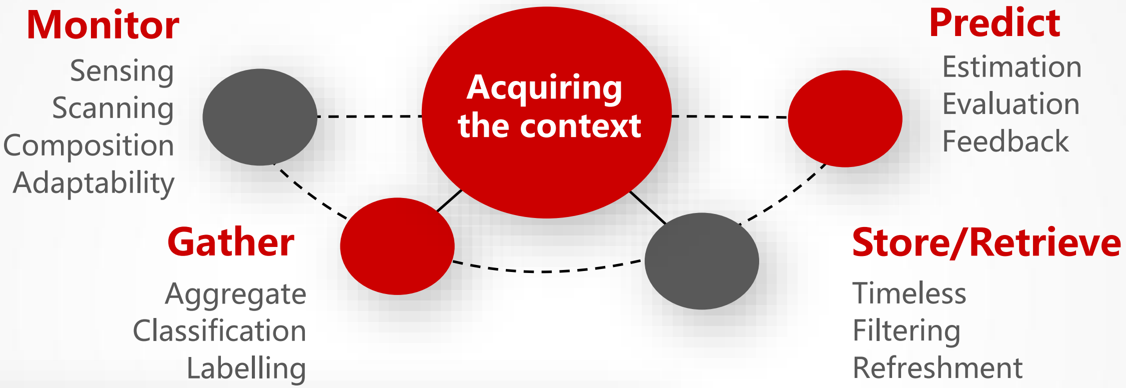
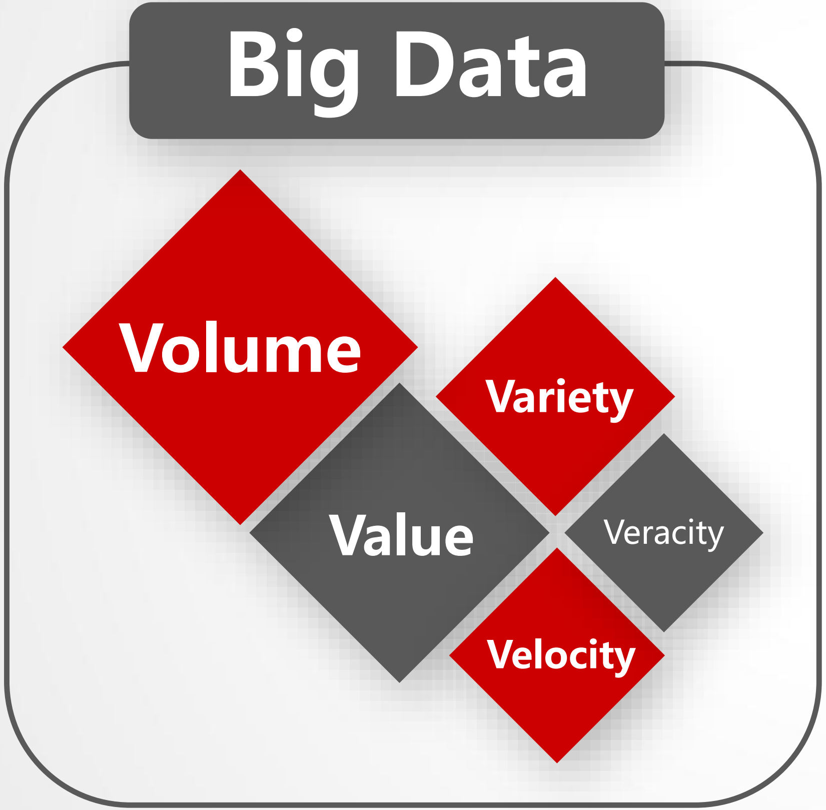
Context-aware in Networked Intelligence



Context-aware functionalities

- Context acquisition
- context modeling
- context exchange
- context evaluation
- exploitation of context
- security, privacy and trust

Big data in Networked Intelligence



Features of Big Data From Networking Perspective

- Distributed Networking
- Heterogeneous Data Representation

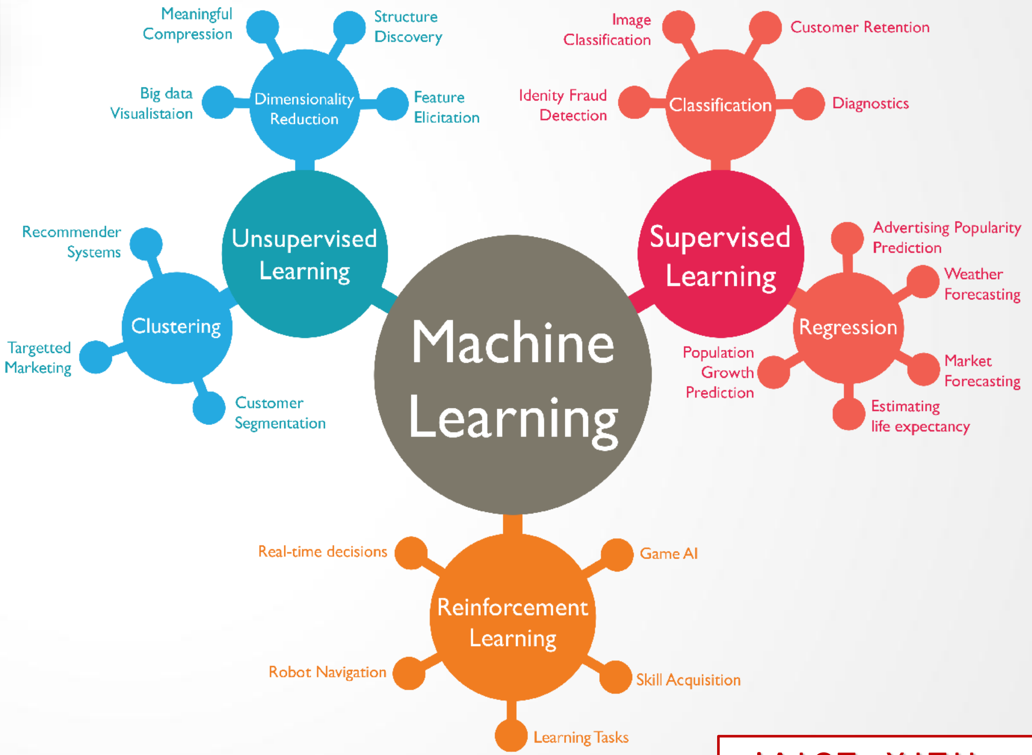
Research challenges and opportunities

- Networking for Big Graph Mining
- Heterogeneous Network Analysis
- Dynamic Representation in Networking for Big Data
- Time Evolving in Networking for Big Data
- Scheduling in Networking for Big Data
- Security in Networking for Big Data
- Privacy in Networking for Big Data

Machine Learning in Networked Intelligence

Advantage of Machine Learning

- Based on big data
- Capability
  - Identification
  - Classification
  - Prediction
  - Execution
  - Learning
  - Comprehension
  - Inference
  - Fuzzy learning
  - Cooperation



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The effect of Machine Learning in Networked Intelligence

- To be aware of the runtime status of the network.
- To make the right decisions to adjust the policies for the traffic control.
- To dynamically change the policies according to the analytics results.

Description Model

- Traffic classification
- Service identification
- Service classification
- Service awareness
- Low-level awareness
- Decision mechanism
- Network Arrangement
- … …

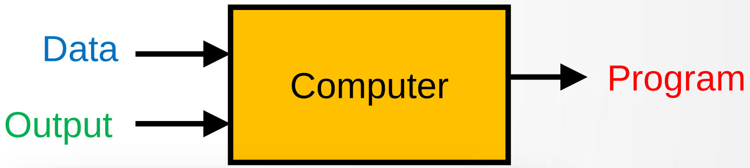
Prediction Model

- Traffic prediction
- Mobility prediction
- Failure prediction
- Content-popularity

Prediction

- Human activity prediction
- Status prediction
- … …

Machine Learning



Estimation Model

- Network security
- Information security
- QoS
- QoE
- Failure detection
- KPI
- Network optimization
- … …

Why Machine Learning is Indispensable?

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Network Security

- 1/3 of traffic is malicious packets generated by software programs.
- A new malware is generated every 4.2 seconds.
- The best human brain can not keep pace with this fast-changing attack strategy.
- Unable to push new defense patches timely to each endpoint, device or network.

Advantage:

I. Capable of resolving thousand of logs per second.
II. Capable of identifying potential threats that humans can't see.
III. Fast response based solutions based on Machine Learning.

IoT

- Perception layer: High-level information carried by photos, videos, etc. could be obtained by Machine Learning.
- Network layer: Under the pressure of a large number of networked devices and sensors, SDN + Machine Learning could be an effective network architecture.
- Application layer: Big data is the most important application scenario of IoT, and Machine Learning is a profitable solution to big data.

Many other scenarios : SDN, Application Driven Network, Industrial Internet, etc.

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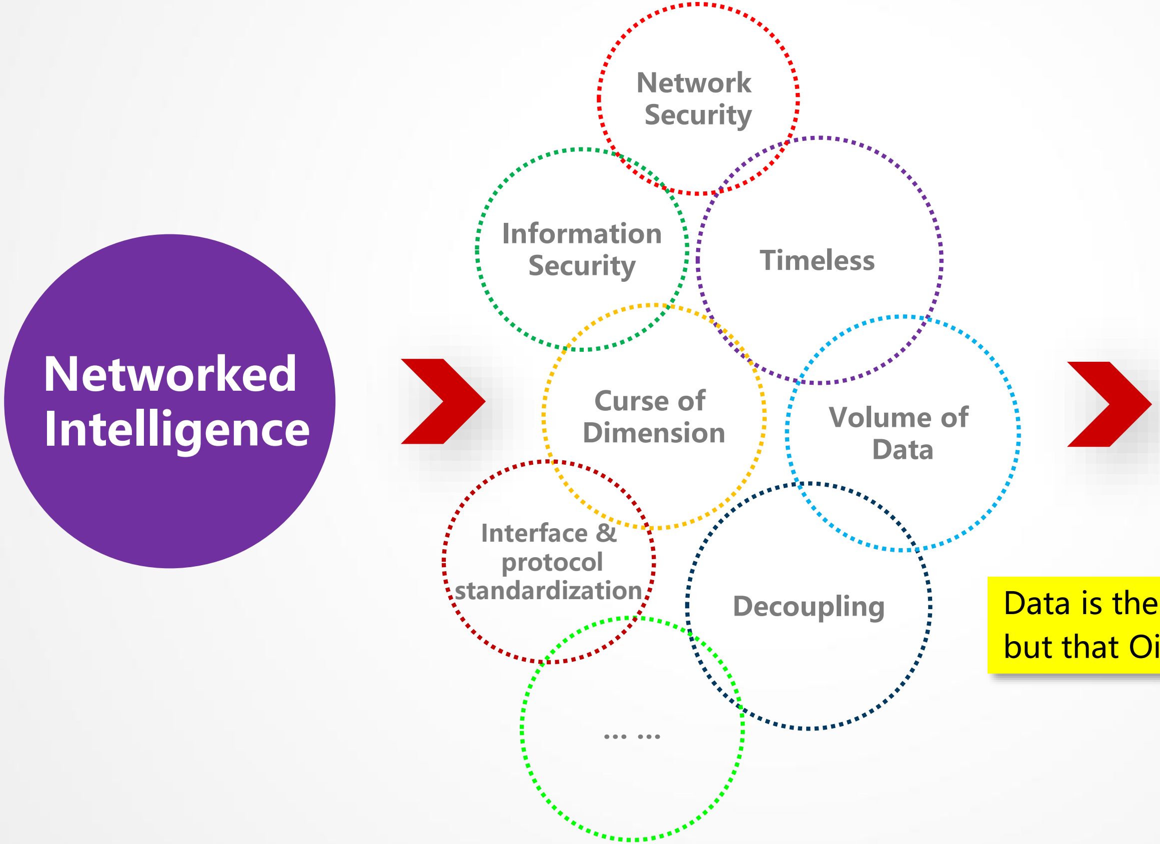
Challenges of Networked Intelligence

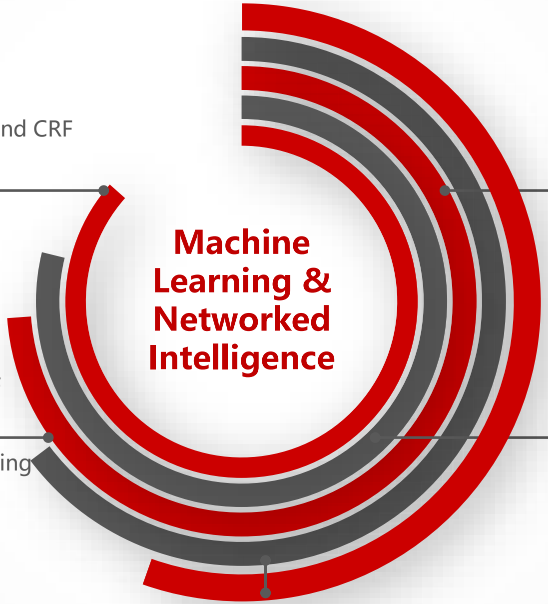


Data is the next Oil –
but that Oil is named Artificial Intelligence

Formation of Our Researches

Big data
- Fine-grained Classification based on Deep Learning and CRF
- Image recognition based on Deep Learning and CRF
- Hybrid Handover Prediction Mechanism
- Network Traffic Classification and Deep Learning

Network Infrastructure
- Hybrid Handover Prediction Mechanism
- Cooperative Caching Expansion Mechanism
- A Joint Sensing and Transmission Power Control policy
- Switch Dynamic Migration Method based on Machine Learning



Intelligent Algorithm
- Fine-grained Classification based on Deep Learning and CRF
- Image Recognition based on Deep Learning and CRF
- Hybrid Handover Prediction Mechanism
- Switch Dynamic Migration Method based on Machine Learning
- Machine Learning-based QoE Factors Identification
- Deep learning-based traffic matrix prediction

Network Architecture
- Self-Organizing Networking in mmWave Backhaul Network
- SDN Self-Management and Control Intelligent System Architecture
- Self-Healing Mechanism based on Statistical Learning
- SDN

Context-aware
- Machine Learning-based QoE Factors Identification
- Deep learning-based traffic matrix prediction
- Network Traffic Classification and Deep Learning
- Survivable Controller Placement Strategy based on Reliability Awareness

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Machine Learning-based QoE Factors Identification

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Demands

Investigate the relationship between use-oriented QoE and network- oriented QoS parameter, in addition to Quality of Application (QoA) parameter and Quality of Device (QoD) parameter.

Techs

Two steps contributing to the accurate identification of QoE factors

- Statistical feature selection according to QoE metrics (e.g., PCA, NMF)
- QoE factors identification based on supervised learning (e.g., SVM, DT)

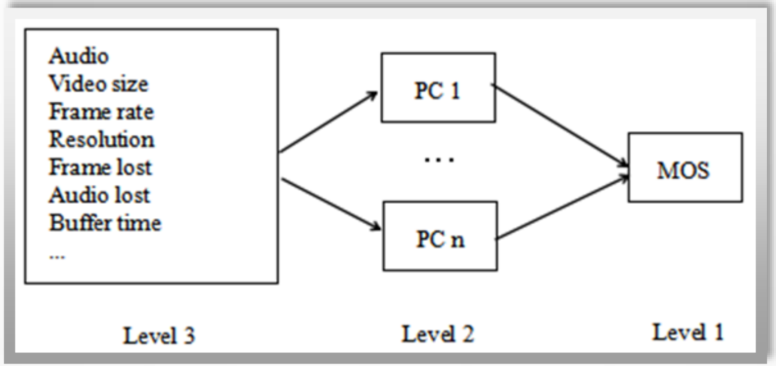

Fig. ML-based QoE factors identification

QoS-QoE Prediction based on Deep Learning

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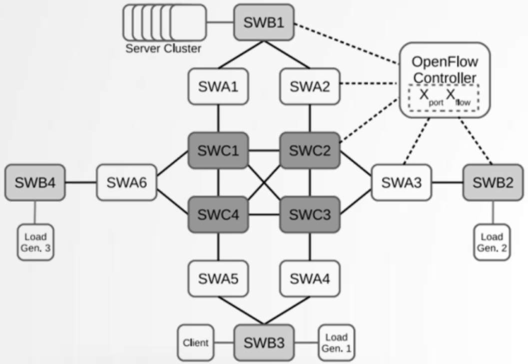
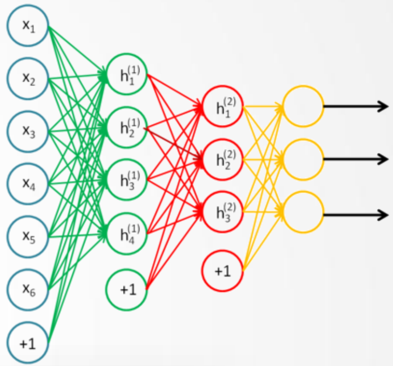


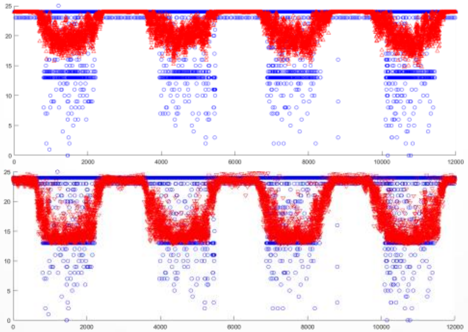
Implementation

1. The method realizes the prediction of service-layer QoS parameters by deep learning algorithm.
2. Based on the predicted QoS reduction, the model is established to obtain the compensation of flow bandwidth of hardware devices (such as switch).



Data Source

We formulate a POMDP framework to derive a joint spectrum sensing and transmission power control policy to achieve the maximum expected throughput .



Advantages

1. The method reduces the load consumption in client
2. The algorithm has better robustness and generalization ability
3. the algorithm is completely transparent to users

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Deep Learning-based Traffic Matrix Prediction

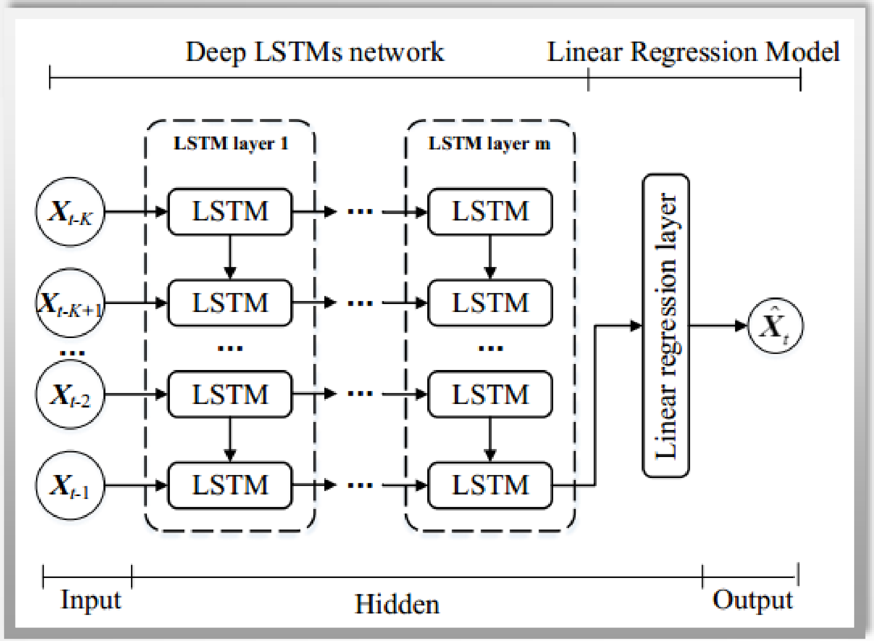


Fig. The DL-based TM prediction architecture

Demands

Traffic matrix (TM) prediction is widely used in network planning, resource management and network security. To achieve accurate and timely TM prediction helps to react network changes in near real-time.

Techs

Based on long short term memory (LSTM) recurrent neural network (RNN), a deep learning-based TM prediction architecture was proposed as this figure described.

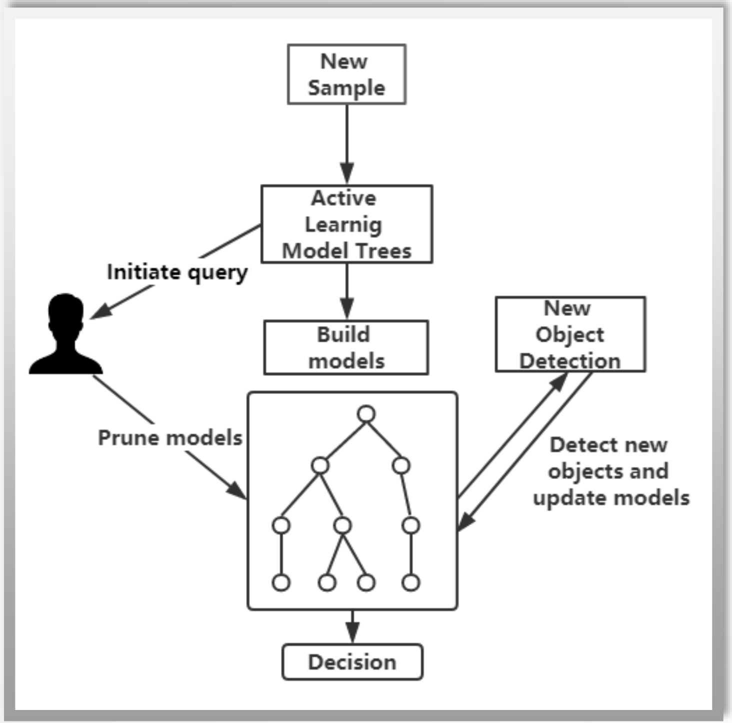


Fig. Architecture of ALDTC

Problems of Traffic Classification

- High accuracy
- Real time classification
- Zero-day traffic identification
  zero-day traffic is the major portion of unrecognized data.

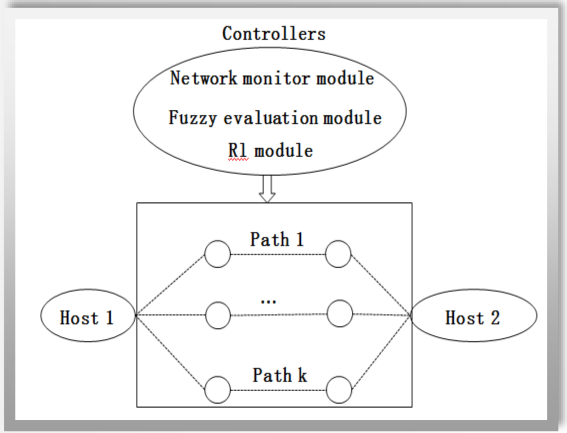
Techs

- A classifier with information-theoretic features.
- An active learning algorithm
  maintains an ensemble of these classifiers, representing alternate hypotheses
- A new object detection algorithm
  works on the outlier bin to determine if a subset of those samples represents a new object

Congestion Control in SDN Networks

Background

In IoT, congestion of network links could be rapidly increased. Our object is to resolve the congestion problem in networks.



Techs

I. Link utilization is calculated in SDN controller and evaluated by the fuzzy Logic module in controllers.

II. The RL module of controllers reaccess the path in networks considering QoS reward values of network.

III. The controllers reallocate paths between network nodes.

Plans without machine learning often cause congestion in network as well as the reduction of network QoS !

The advantages of machine learning:

- Fuzzy logic module can access network paths quality accurately and comprehensively.
- RL module evaluates the long time conditions of network paths.
- The combination of these two module achieve the goal to select the best paths for data transmission.

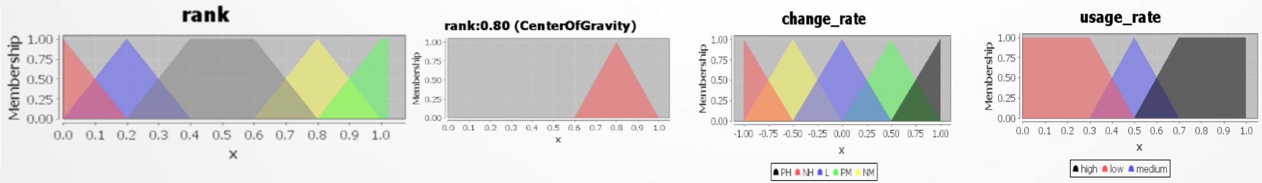


Fig. The results of fuzzy evaluation module

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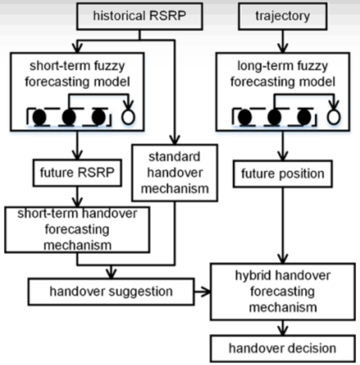
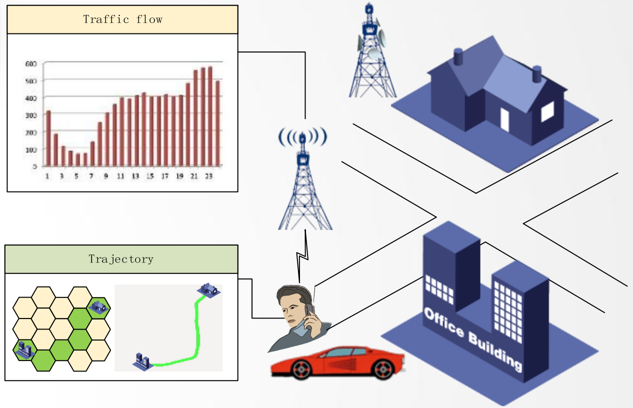
Hybrid handover prediction mechanism

Techs:

- Long-term model for trajectory prediction
- Short-term model for RSRP prediction
- Hybrid handover mechanism





Scenario: The reduction of coverage of cells makes the handover decision more difficult. Future mobility could help with handover management.

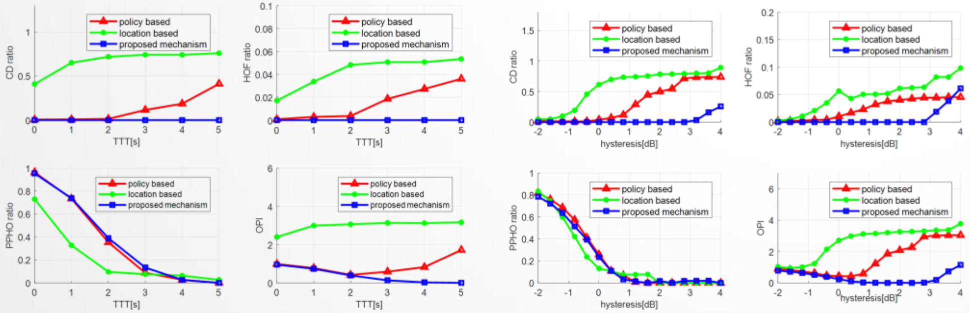


Fig. Simulation result of the performance of different TTTs and hysteresises.

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Hybrid Handover Prediction Mechanism

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Fuzzy Prediction Model

A four-step framework to make forecast:

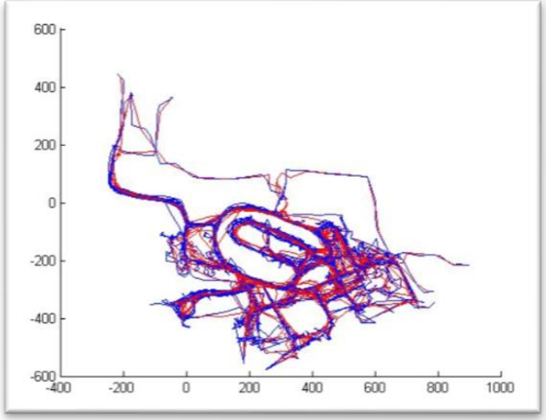
I. Define the universe of discourse and partition it into intervals;

II. Determine the fuzzy sets and fuzzify the time series;

III. build the model of fuzzy logic relationships;

IV. make forecast and defuzzify the forecast values.

Fig. Forecasting results of trajectories.



Why predict?

- Future condition is more important when making handover decision.
- Wrong handovers are mainly caused by the lack of the future information.
- Forecasting results is accurate enough.

Fig. Forecasting results of the data in both training set and testing set by using the fuzzy forecasting model, and the actual values.

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Cooperative Caching Expansion Mechanism

The Proposed Mechanism

Background: Limitation of Caching Store (CS) is the main bottleneck of ICN. The cooperation between neighbor nodes can help expand the caching size of CS.

Techs:

1. Classify the content into S categories;
2. Each node formulate a cooperative group with its neighbor nodes, which caches different category of content;
3. When making content caching decisions, each node only caches those contents of its category.

Simulation Results

The mechanism can reduce the average hit hops, missing rate, content replacement times, and can improve hit ratio.

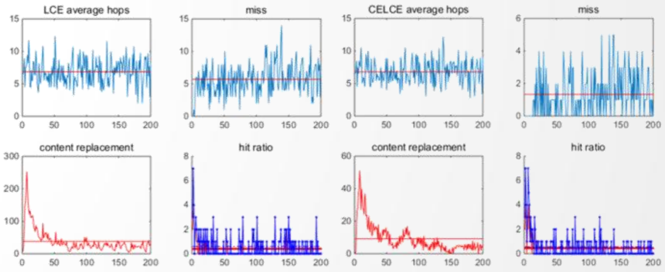

Fig. Simulation result of LCE and LCE-CCE.

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A Joint Sensing and Transmission Power Control Policy

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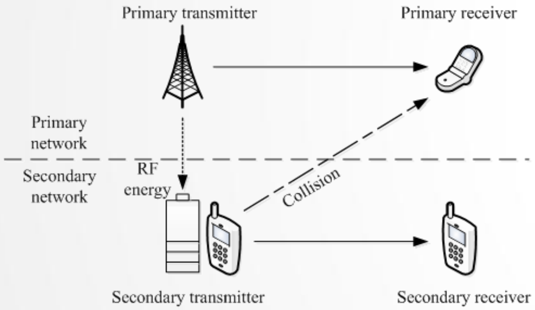
Scenario: We consider an RF energy harvesting cognitive radio network, in which the channel occupancy state and the channel fading level are both model as discrete Markov processes.

Objective: We formulate a POMDP framework to derive a joint spectrum sensing and transmission power control policy to achieve the maximum expected throughput .



Contribution

1. We obtain the channel state information by the sensing outcome, the ACK message and the harvesting outcomes.
2. We employ a point-based value iteration algorithm to obtain the approximate solution of our proposed policy

The advantage in employing the POMDP framework:

I. The POMDP framework can capture the fundamental design tradeoff between gaining immediate access and harvesting energy for future use.
II. The channel occupancy state cannot be fully observed due to sensing errors.
III. The channel fading state information is only partially observable through the ACK message.

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Self-Organizing Networking in mmWave Backhaul Network

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Fig. Grid Mesh HetNet Overlaying eNB with mmWave Backaul.

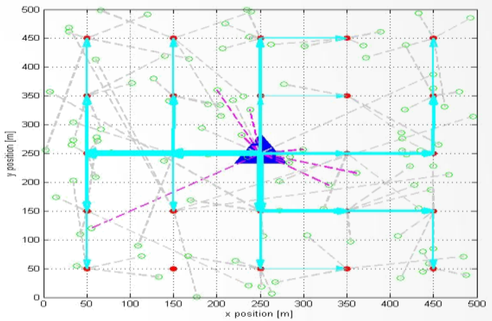

Fig. UE-BS association and Backhaul topology at 26Mbps Demand rate per user [proposed method].

$$ABJEE[BS]: \quad EE_{ABJ,i} = \frac{r_i^{acc}}{p_i^{acc} + p_i^{bkl}}, \forall i \in \{0\} \cup S$$

$$ABJEE[System]: \quad EE_{ABJ} = \frac{\sum_{i \in \{0\} \cup S} r_i^{acc}}{\sum_{i \in \{0\} \cup S} \left(p_i^{acc} + p_i^{bkl}\right)}$$

The Adopted ABJEE (Access and Backhaul Joint Energy Efficiency)

Our Work focus on the self-organizing of UE-BS association at access network using <6GHz microwave transmission and wireless backhaul transmission at transport network using 60GHz mmWave transmission. The aim of our work is to find a low-complexity algorithm to solve this joint optimization problem, comparing with conventional MILP solution, such as branch and bound searching (BnB).

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The original Utility Function (MILP) aiming at optimizing the system ABJEE performance

$$\min \underbrace{\sum_{i\in\{0\}\cup S}\sum_{j\in U(i)} x_{i,j}^{acc}\, p_{i,j}^{acc}}_{\text{AN power consumption}} + \underbrace{\sum_{i\in\{0\}\cup S}\sum_{h\in\{0\}\cup S,h\neq i} x_{i,h}^{bkl}\, p_{i,h}^{bkl}}_{\text{BH power consumption}}$$

$s.t.$

$$(1)\, r_{i,j}^{acc} \geq r_{\min}, \forall i\in\{0\}\cup S, j\in U(i)$$

$$(2)\begin{cases} \sum_{j\in U(i)} r_{i,j}^{acc} + \sum_{k\in O(i)} x_{i,k}^{bkl} r_{i,k}^{bkl} = \sum_{h\in I(i)} x_{h,i}^{bkl} r_{h,i}^{bkl}, \forall i\in S \\ \sum_{i\in S}\sum_{j\in U(i)} r_{i,j}^{acc} = \sum_{h\in O(0)} x_{0,h}^{bkl} r_{0,h}^{bkl} \end{cases}$$

$$(3)\, p_{i,j}^{acc} \geq 0,\; p_{i,h}^{bkl} \geq 0,\; \forall i\in\{0\}\cup S, j\in U(i), h\in\{0\}\cup S$$

$$(4)\, \sum_{j\in U(i)} p_{i,j}^{acc} \leq p_{\max,i}^{acc}, \sum_{j\in U(i)} r_{i,j}^{acc} \leq r_{\max,i}^{acc}, \forall i\in\{0\}\cup S$$

$$(5)\, x_{i,j}^{acc}, x_{i,h}^{bkl} \in \{0,1\}, \sum_{i\in\{0\}\cup S} x_{i,j}^{acc} \leq 1, \forall j\in U$$

$$(6)\, r_{i,j}^{acc}\cdot BIG \geq x_{i,j}^{acc}, x_{i,j}^{acc}\cdot BIG \geq r_{i,j}^{acc}$$

$$(7)\, r_{h,i}^{bkl}\cdot BIG \geq x_{i,h}^{bkl}, x_{i,h}^{bkl}\cdot BIG \geq r_{h,i}^{bkl}$$

Why applying machine learning to this problem:

Since the network complexity and user traffic dynamics becomes highly nonlinear and non-convex in terms of network scale, traditional analytic tools are intractable in dealing with these problems, including ultra-dense networking problem. Data-driven methodology are much more favorable. Machine learning tools are usually applied to create strategies and rules to optimize system-wide performance and user-centric metrics, such as support vector machine (SVM), and deep learning (DL) neural network.

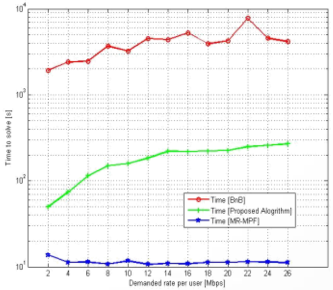

Fig. ABJEE performance. Our algorithm yields a little worse performance in ABJEE, since it sacrifices optimality for algorithm complexity.

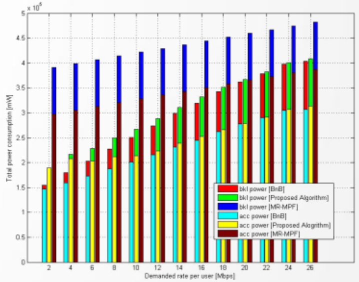

Fig. Algorithm Complexity. The proposed algorithm outperforms the conventional BnB method in execution time.

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Fine-grained Classification based on Deep Learning and CRF

Demands: Dense pixel-level structured classification is applied in some particular tasks like self-driving, intelligent medical and NLP.

Techs: Designing models based on deep learning and CRF models to exploit high and low level features, local and global spatial connection for pixel-level classification.

Data: Pixel-level annotated datasets.

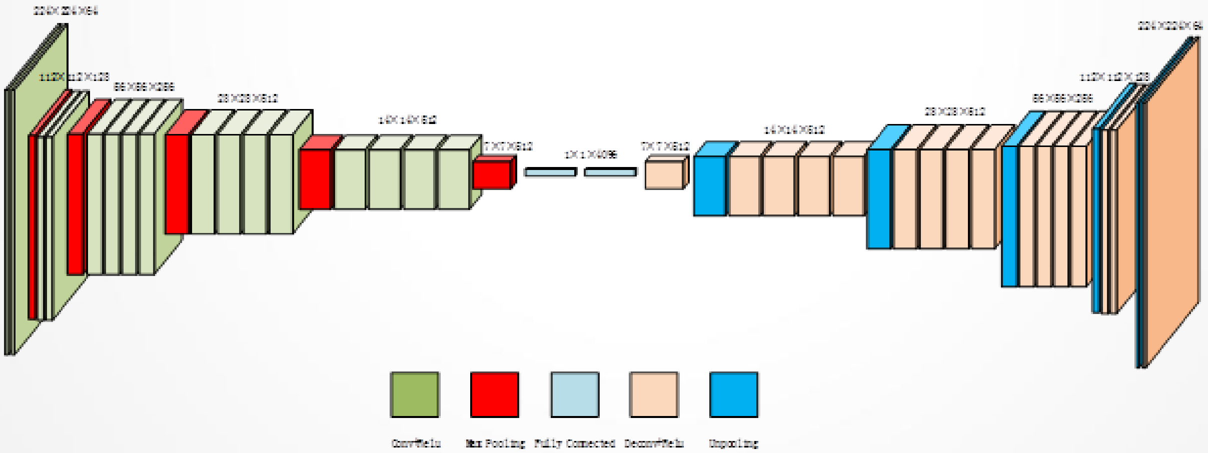


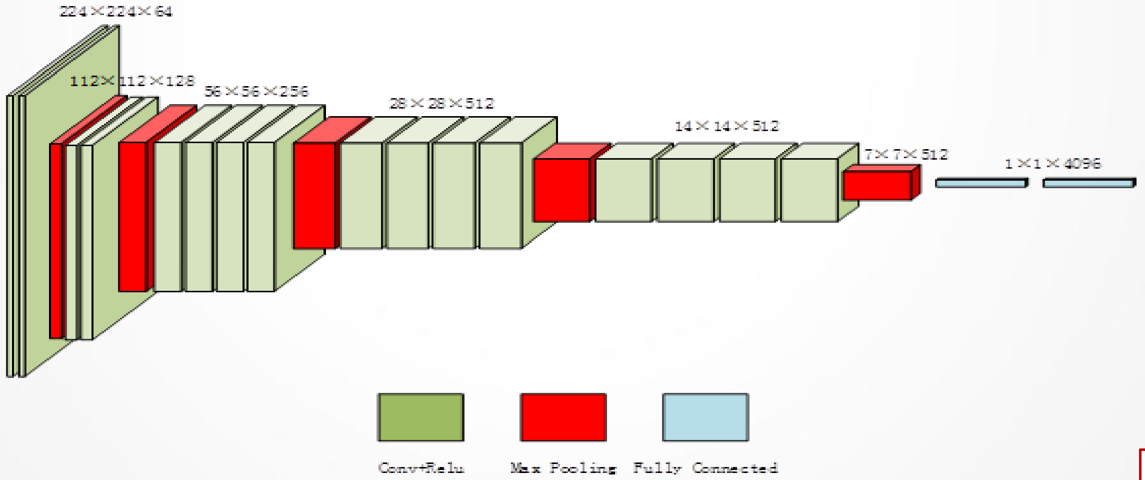
Image recognition based on Deep Learning and CRF

XI'AN JIAOTONG UNIVERSITY

Demands： Deep learning models are easily fooled by adversarial examples to make mistakes.

Techs： Designing models based on deep learning and CRF models to exploit high and low level features, local and global spatial connection for improving robustness.

Data： Labeled datasets.



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THANKS