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Machine Learning for 5G RAN

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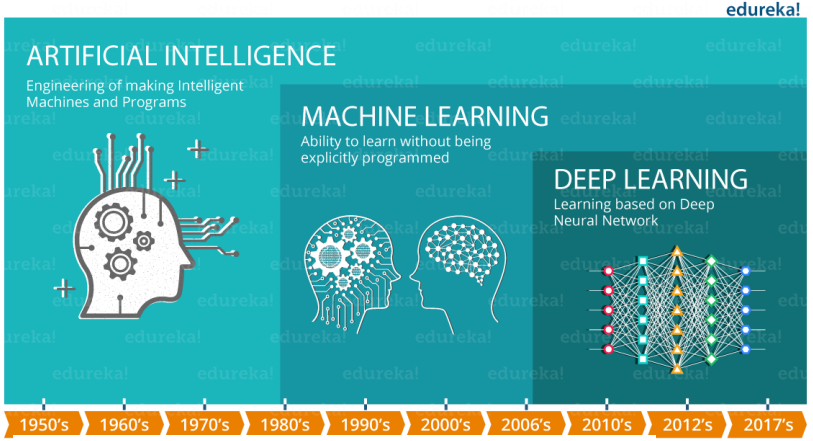
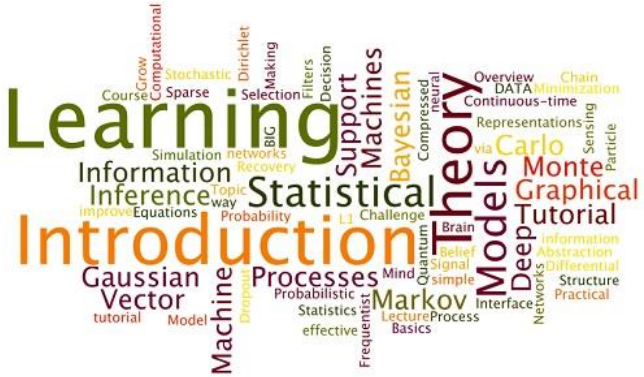
What is Machine Learning (ML)?

- Arthur Samuel (1959): **Machine learning** is a field of computer science that uses statistical techniques to give computer systems the ability to "**learn**" (i.e., progressively improve performance on a specific task) with **data**, without being explicitly programmed

- Recent resurgence based on:
  - Data
  - Massive computing - Hardware
  - Algorithms – Software and Applied Math/Stats/EE Systems

- Used for (some examples):
  - Optical character recognition, Speech recognition
  - Web search
  - Human genome analysis
  - Self-driving cars
  - Many, many more





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What can AI/ML do for networks?
Opportunities and Challenges

Opportunities

- Value Added Services: New revenue streams, business models
- Improve network and user performance
- Reduce complexity
- Increase Automation: Reduce R&D effort

Challenges

- Significant gains of AI/ML only expected in complex scenarios that are hard to model
- Today, gathering even simple data is difficult; gets even more challenging with 5G (2000+ parameters for a typical 5G node; 50x operational complexity increase from 4G to 5G)
- Legacy networks not designed for AI, need to rethink/rebuild

Pursue the opportunities holistically and address the challenges systematically

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AI/Machine Learning for RAN
Holistic Solution Architecture

Two buckets of use cases/applications:

- **on-top-of-the-RAN [1-3]**
- **embedded-in-the-RAN [4-6]**

Key building blocks:

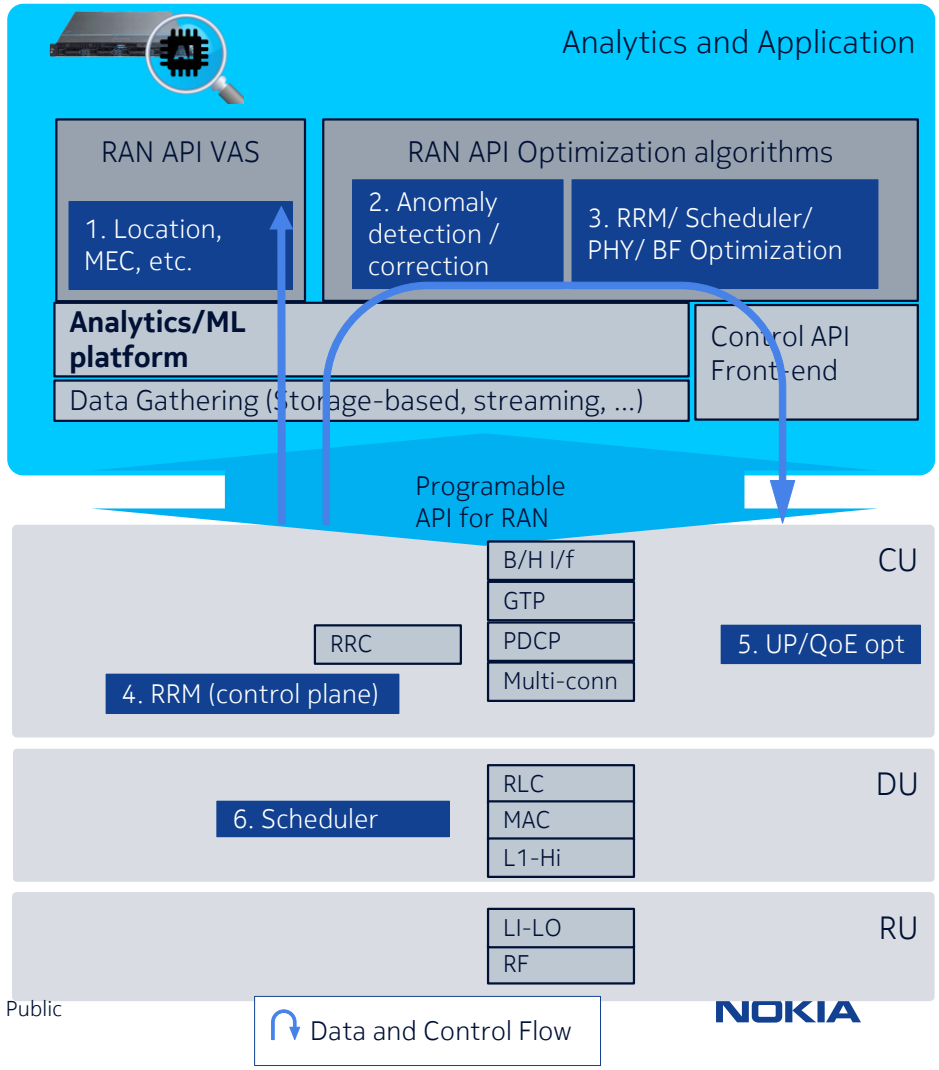
A. **Innovative AI/ML Algorithms @ RAN** solve most complex problems and provide differentiation

B. **New RAN communications interface** enables a networked Intelligence

C. **AI/ML platform, middleware, toolkit** @ edge of the network creates digital value

D. **AI/ML HW** accelerators provide raw computational power for AI/ML

➔ **Holistic Solution Architecture**



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AI/Machine Learning for RAN
Systematic Step-by-step Solution

Step-by-step approach helps in systematically realizing the potential of AI/ML in RAN

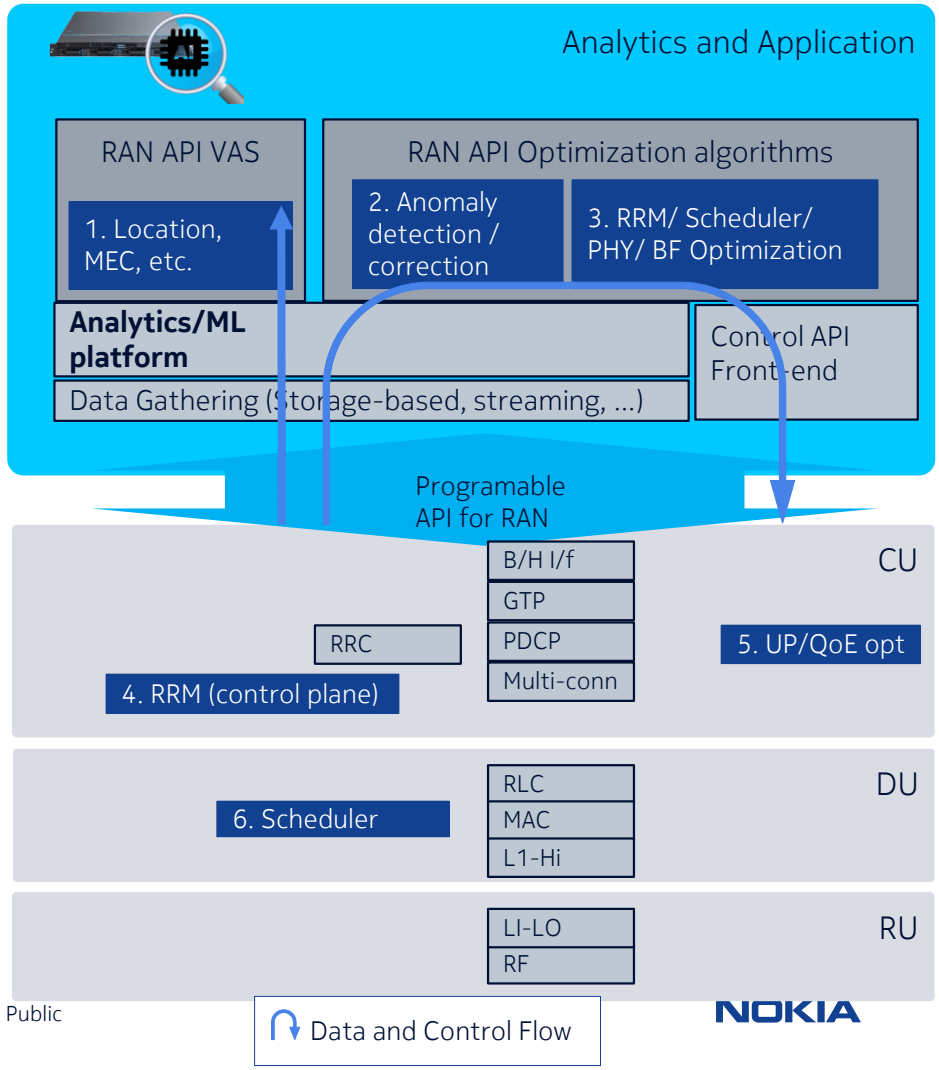
I. **Step I - Moving beyond the hype: Study and Identify areas where AI/ML can make a substantial difference in terms of performance or complexity/TCO**

II. **Step II – Build the foundation with 4G:** Develop (a) **Algorithms based on AI/ML on top of existing 4G RAN** based on (b) a **Programmable API** for data exposure and control, and (c) a **Platform and Middleware** for data gathering, analytics and machine learning platform. Algorithms can also be extended to 5G.

Extensive work ongoing on Steps I & II

III. **Step III – Prepare the ground for 5G**: Develop **Algorithms based on AI/ML embedded in the 4G/5G RAN** leveraging from Phase II, with enhancements the Platform and Middleware, for data gathering, analytics and machine learning platform.

Concurrent work on Step III as these are long lead items



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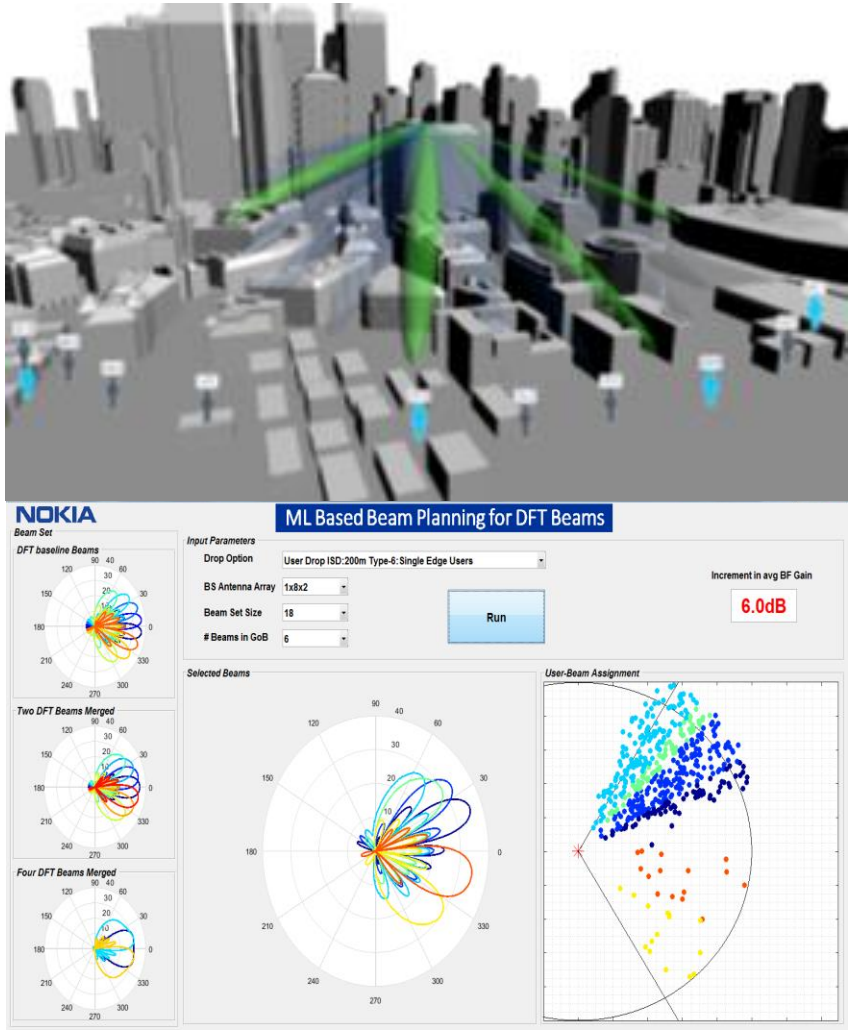
Algorithms for Use Cases/Applications

A few examples

- Indoor Location
  - Need RF fingerprint along with location data for training
- UL Control/CQI RRM Optimization
  - Rely on simulation for offline training, but also need field data for online learning of cell/time specific variations which are hard to model
- Scheduler for 5G massive MIMO
  - Combinatorial complexity is prohibitive to do exhaustive search (beyond greedy heuristic algorithms). ML with massive offline training based on simulations is useful to approximate optimal solutions.
- Beam Pattern Optimization for massive MIMO
  - Solution dependent on cell topology/ propagation as well as user traffic variations which are hard to model.



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AI Powered RAN

Some Concluding Thoughts

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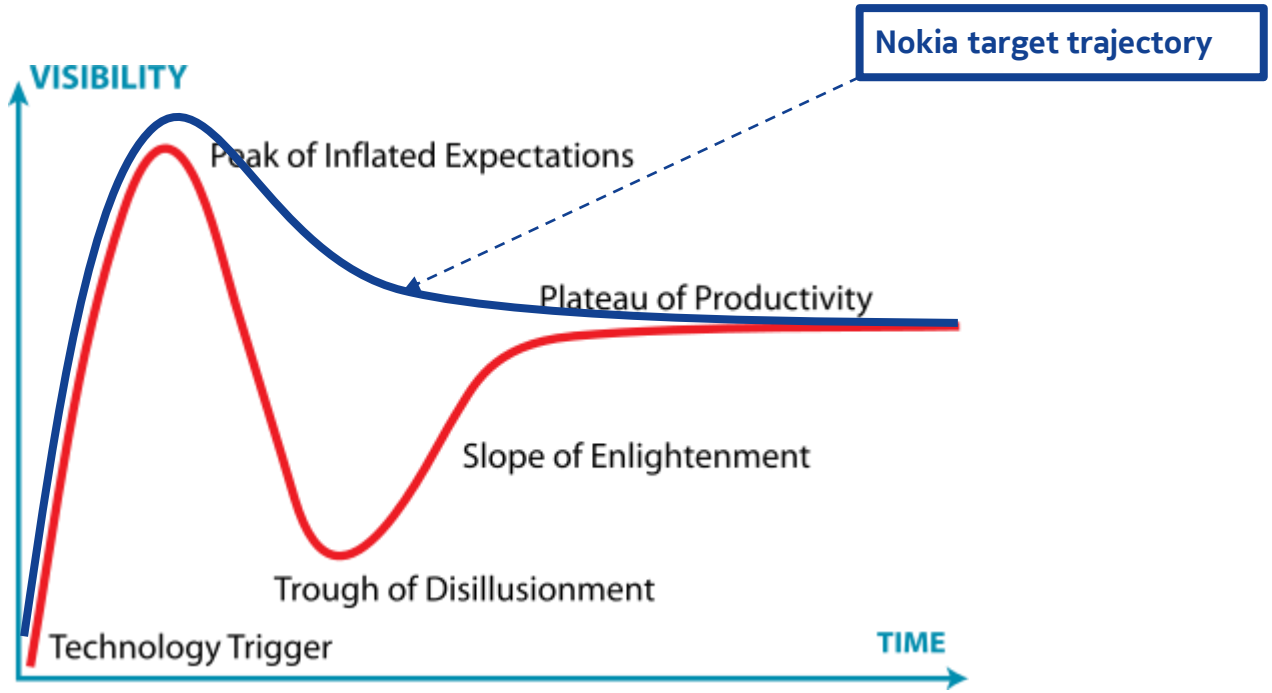
AI-powered RAN - Hype Cycle
Need to go beyond the hype!



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Holistic and Systematic Step-by-step Solution

Way Forward

2 buckets of use cases/application/algorithms

- on-top-of-the-RAN
- embedded-in-the-RAN

4 key building blocks that help frame and differentiate Nokia solution

A. Algorithms
B. RAN API
C. ML Platform, Middleware, Toolkit
D. HW acceleration (ReefShark, data center)

Step-by-step approach (building on previous steps)

I. **Go beyond hype** and study in-depth and design good algorithms
II. **Start with Algorithms on-top-of-the-RAN**, **API, ML Platform**
    Don't need major surgery on RAN and can do easily with existing/classical RAN without embedded algorithms
    Can start with 4G and extend to 5G
    Use this to engage customers, **collect and analyze real network data**
III. Design, study and develop **embedded-in-the-RAN** algorithms along with **HW acceleration** dimensioning and IP blocks

Specific application/use case/algorithm may or may not be successful, but taken collectively some will succeed, so business case should be built on

- **taking these collectively**, putting framework with building blocks in place
- Deciding on specific application/use case/algorithm as **"features"** later when detailed studies have been

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