Talk on Data Science: Unsupervised Learning for Root Cause Analysis

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Presentation Agenda

Brief Introduction – 5 mins

Recent research on Data Science (Root Cause Analysis) – 25 mins

Q&A

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Brief Introduction

Highlights

- Senior Principal Consultant, Machine Learning and Wireless Communications at Nokia Bell Labs 2020-Present
- Adjunct Assistant Professor of Electrical and Computer Engineering at University of Texas at Dallas, Fall 2021-Spring 2022
- Director, Radio Performance Assurance and Engineering at Samsung Electronics America 2019-2020
- Over 18 years of industry experience in cellular communications. Held various senior and leadership roles at Motorola, Ericsson, Samsung, and Nokia
- Research interests are in machine learning and its applications in the next-generation radio access networks (5G and beyond)
- Academic credentials:
  - Ph.D. in Electrical and Computer Engineering, University of Texas at Austin, 2019
  - MBA, University of Texas at Dallas, 2014
  - MS in Electrical Engineering, University of Texas at Dallas, 2011
  - BS in Computer Engineering, University of Jordan, 2004

Brief Introduction

Awards and professional society services

Awards

- 2022, Invited paper to IEEE 95th Vehicular Technology Conference
- 2021, Nokia Fearless Leadership Award
- 2020, Nokia STAR Award (also in 2021)
- 2017, Elevated to IEEE Senior Member
- 2016, Marcus Wallenberg Foundation Scholarship for Scientific Research and Education (Ph.D. full scholarship)
- 2015, Ericsson recognition for my efforts in the Ericsson v Apple global patent litigation
- 2014, UT Dallas Dean's Excellence Scholarship for Continuing Graduate Students Award
- 2013, Ericsson Key Contributor Award
- 2012, UT Dallas School of Management Dean's Excellence Scholarship Award
- 2009, Ericsson North America outstanding recognition (also in 2010 and 2011)
- 2006, Motorola BRAVO! Award (also in 2008)
- 2004, Jordanian Engineers Association Best Senior Project Award
- 2004, The University of Jordan Board of Trustees Award for Academic Excellence

Professional Society Services

- Many invited talks at universities (Harvard and Texas A&M) and corporates in different organizations and regions (Ericsson Sweden and India; Samsung Engineering and Technology Services; and Nokia Global)
- Reviewer for IEEE Network Magazine, IEEE Transactions on Communications, IEEE Transactions on Wireless Communications, IEEE Vehicular Technology Society, IEEE International Conference on Communications, IEEE Communications Magazine, IEEE Globecom, IEEE Wireless Communication Letters (exemplary reviewer), and IEEE Communication Letters.

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Research on Data Science

Most recent journal publication

Unsupervised Learning in Next-Generation Networks: Real-Time Performance Self-Diagnosis

Faris B. Mismar, *Senior Member, IEEE*, and Jakob Hoydis, *Senior Member, IEEE*

Featured on Bell Labs' website: https://www.bell-labs.com/institute/publications/scopus85112618669/

F. B. Mismar and J. Hoydis, "Unsupervised Learning in Next-Generation Networks: Real-Time Performance Self Diagnosis," in *IEEE Communications Letters*, vol. 25, no. 10, pp. 3330-3334, Oct. 2021.

Unless otherwise stated, all material on the slides in this section is based on or builds upon this journal paper. The presenter requests if you use these slides or any herein modified part of it in any publication, please cite this journal paper.

Research on Data Science

Motivation and approach

- **Problem**
  - Live networks often suffer from degraded performance
  - Finding the root cause for this degradation is time consuming and often subjective

- **Goal**
  - Perform root cause analysis (RCA), which is a cognitive task aimed at finding the reason for an anomaly over a window of interest, in linear time in the number of learning features in the observability dataset

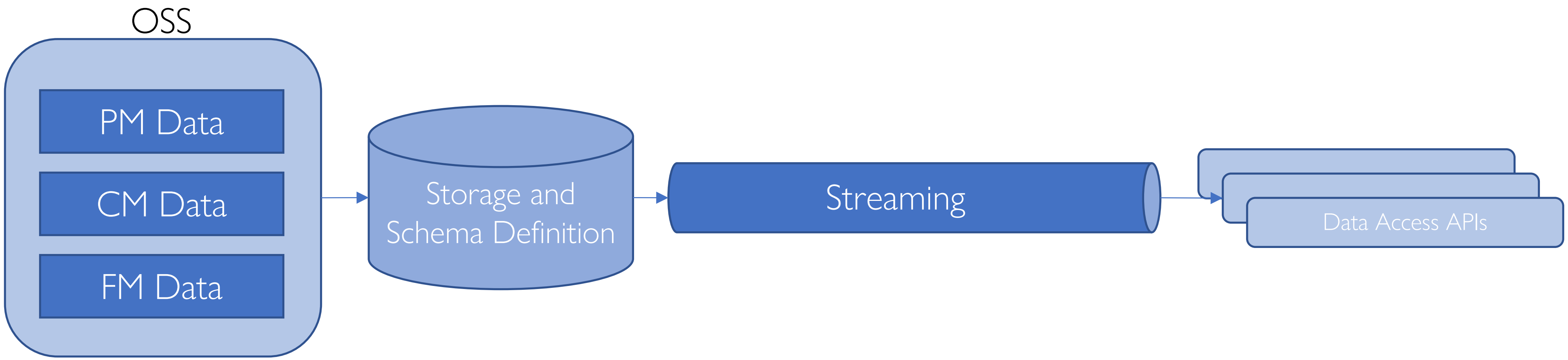
- **Approach**
  1. User calls the entry point through an application programming interface (API) to a private cloud instance
  2. This streams the network *data* (through another API) onto the compute engine on the cloud instance
  3. The compute engine deploys a machine learning *code* container that implements the proposed algorithm which runs as a microservice and publishes results in a specific format.

Improve execution efficiency through automation of a cognitive task

Research on Data Science

Data: architecture

- In telecommunication networks, network data recording is performed in the operations support subsystem (OSS). Broadly three types of data are recorded: performance management (PM), configuration management (CM), and fault management (FM).



Slide re-used and modified from my talk, "Machine Learning in Telecommunications: Automation and Profitability," an invited online presentation to Harvard Business School, Cambridge, MA, USA, Aug. 2021.

Research on Data Science

Data: establish an observability universe

- Data sources are heterogeneous (i.e., some are periodically sampled; others are event driven).
- In order for a learning framework to be applied, an observability design matrix $\mathbf{M} \in \mathbb{R}^{m \times n}$ has to be constructed first. This design matrix is given by

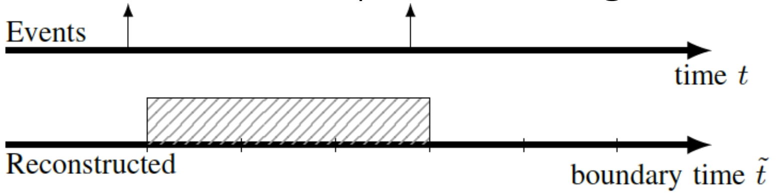
$$\mathbf{M} := [\mathbf{p}_1, \ldots \mathbf{p}_r, \mathbf{f}'_1, \ldots, \mathbf{f}'_p, \mathbf{c}'_1, \ldots, \mathbf{c}'_q] \qquad n = r + p + q$$

Column vectors of PM counters

Column vectors of reconstructed FM events

Column vectors of reconstructed CM changes

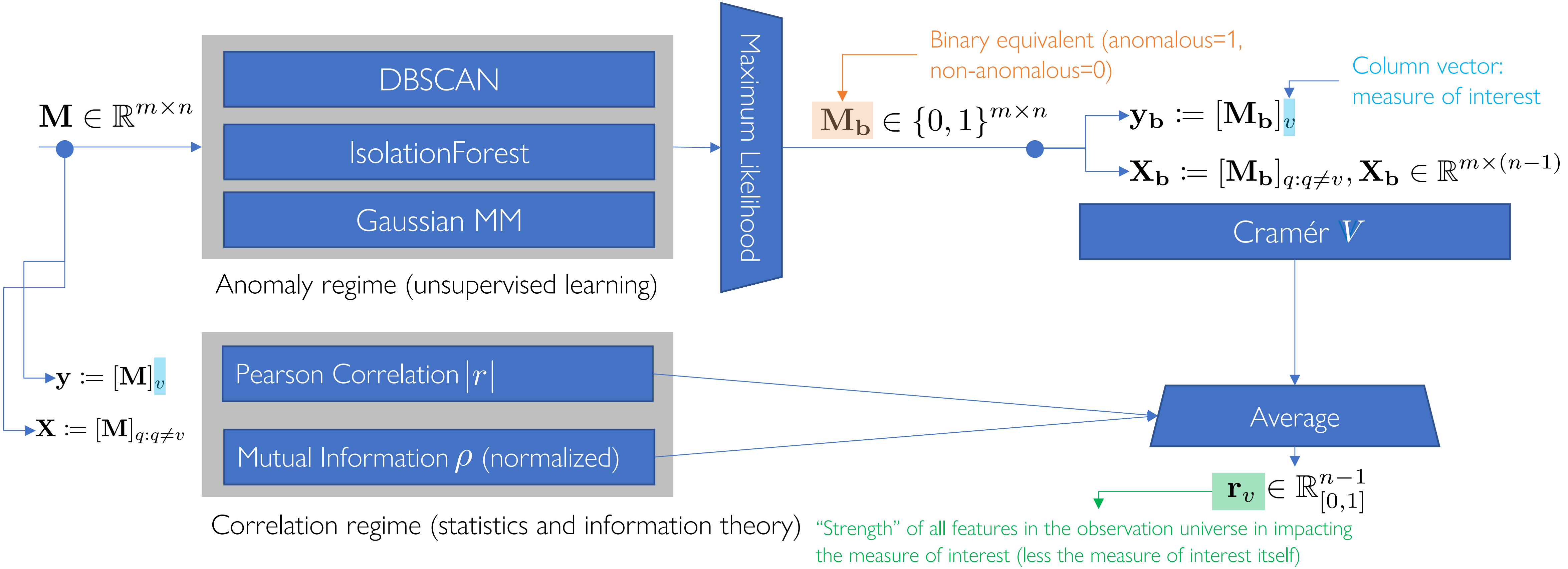
- **Problem**: column vectors (i.e., features) have different dimensions; thus a design matrix cannot be readily constructed.
- **Solution**: reconstruct column vectors. Idea: PM data is periodically sampled every $\Delta T > 0$ time units. For a window of interest $W > 0$, it is straightforward to show that $m := \lceil W/\Delta T \rceil$.
 Reconstructing FM events and CM changes is a matter of temporal binning and "sample-and-hold" or simply integrating the impulse functions over the time until the change effect is over. Temporal binning is done by dividing the window of interest into m equi-distanced intervals.



Research on Data Science

Code: ensemble of learning algorithms

Algorithms are trained using grid search cross validation over all hyperparameters using a log-scale selection of values to maximize V



Now that correlation has been established. What is next?

Research on Data Science

Code: causality framework

- Causality: the causal effect (CE) of X on Y is given by $p(Y = y \mid X = x_1) - p(Y = y \mid X = x_0)$

  manipulated probability

  tolerance

- Causality filter with tolerance $u_\varepsilon^{(i)} = \mathbb{1}[|p(Y_v = y \mid X_i = x_1) - p(Y_v = y \mid X_i = x_0)| > \varepsilon], i \in \{1, 2, \ldots, n-1\}$

  measure of interest

  number of columns in observability matrix

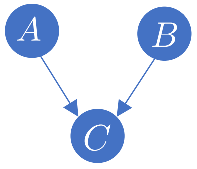
- This finally allows us to exclude all correlations that are not causal:

$$\mathbf{g} = \mathbf{u} \odot \mathbf{r_v}$$

A column vector from the adjacency matrix of a causality graph *aka* "causality filter" $\mathbf{u} := [u_\varepsilon^{(i)}]_{i=1}^{n-1}, \mathbf{u} \in \mathbb{R}^{n-1}$

CE relations from the causality graph

$$|p(C = c \mid A = a_1) - p(C = c \mid A = a_0)| > 0$$
$$|p(C = c \mid B = b_1) - p(C = c \mid B = b_0)| > 0$$



- And return the index of the column of the highest strength (from the design observability matrix):

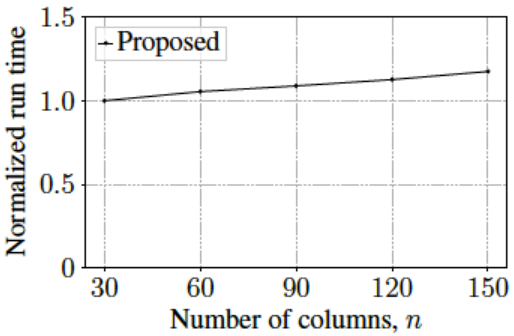
$$i^\star := \underset{i \in \{1,2,\ldots,n-1\}}{\arg\max} \; [\mathbf{g}]_i$$

The root cause of the degradation of measure v over the window of interest W as observed by the matrix $\mathbf{M}$ is $[\mathbf{M}]_{i^\star}$
The strength of this causality is $[\mathbf{g}]_{i^\star}$.

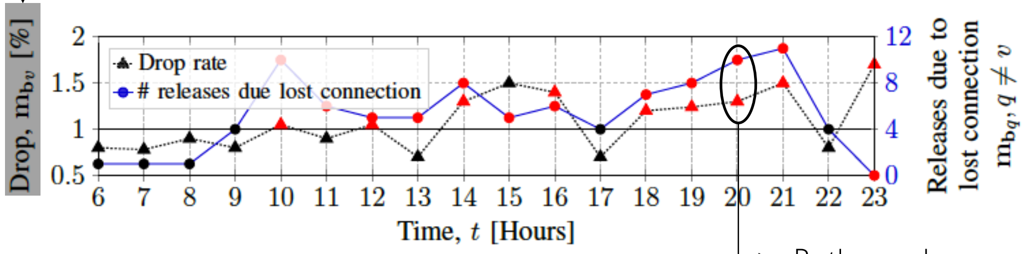
Slide re-used and modified from my talk, "Using Machine Learning in 5G Radio Access Networks," Coppell, TX, USA, Jul. 2020.

Research on Data Science

Results from paper



Any drop rate above 1% is anomalous by design. Average correlation is 0.707



Both v and q are anomalous

Measured against subject matter expert findings

TABLE II
RCA PERFORMANCE

Scenario A		Scenario B	
$W/\Delta T$	Accuracy	$W/\Delta T$	Accuracy
5	0.8913	120	0.9932

- Linear run-time allows expanding the observability universe (i.e., adding more features)
- Short time windows can cause a “myopic” view of the RCA because algorithms have small sample size for a valid learning to be made

RCA can be run autonomously to aid in real-time self-diagnosis of networks

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Q&A

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Thank You!

More applications of data science in cellular communications

Journal Articles – Appeared

[J1] F. B. **Mismar** and J. Hoydis, "Unsupervised Learning in Next-Generation Networks: Real-Time Performance Self-Diagnosis," in *IEEE Communications Letters*, vol. 25, no. 10, pp. 3330-3334, Oct. 2021.

[J2] F. B. **Mismar**, A. AlAmmouri, A. Alkhateeb, B. L. Evans, and J. G. Andrews, "Deep Learning Predictive Band Switching in Wireless Networks," in *IEEE Transactions on Wireless Communications*, vol. 20, no. 1, pp. 96-109, Jan. 2021.

[J3] F. B. **Mismar**, B. L. Evans, and A. Alkhateeb, "Deep Reinforcement Learning for 5G Networks: Joint Beamforming, Power Control, and Interference Coordination," in *IEEE Transactions on Communications*, vol. 68, no. 3, pp. 1581-1592, Mar. 2020.

[J4] F. B. **Mismar**, J. Choi, and B. L. Evans, "A Framework for Automated Cellular Network Tuning with Reinforcement Learning," in *IEEE Transactions on Communications*, vol. 67, no. 10, pp. 7152-7167, Oct. 2019.

[J5] F. B. **Mismar** and B. L. Evans, "Deep Learning in Downlink Coordinated Multipoint in New Radio Heterogeneous Networks," in *IEEE Wireless Communications Letters*, vol. 8, no. 4, pp. 1040-1043, Aug. 2019.

Conferences

[C1] F. B. **Mismar**, "Intermodulation Interference Detection in 6G Networks: A Machine Learning Approach," *Proc. IEEE Vehicular Technology Conference Workshops* (Invited Paper), Helsinki, Finland, Jun. 2022, pp. 1-6, to appear.

[C2] A. Taha, Y. Zhang, F. B. **Mismar**, and A. Alkhateeb "Deep Reinforcement Learning for Intelligent Reflecting Surfaces: Towards Standalone Operation," Proc. *IEEE International Workshop on Signal Processing Advances in Wireless Communications*, Atlanta, GA, USA, May 2020, pp. 1-5.

[C3] F. B. **Mismar** and B. L. Evans, "Deep Q-Learning for Self-Organizing Networks Fault Management and Radio Performance Improvement," Proc. *IEEE Asilomar*, Pacific Grove, CA, USA, Oct. 2018, pp. 1457-1461.

[C4] F. B. **Mismar** and B. L. Evans, "Q-Learning Algorithm for VoLTE Closed-Loop Power Control in Indoor Small Cells," Proc. *IEEE Asilomar*, Pacific Grove, CA, USA, Oct. 2018, pp. 1485-1489.

[C5] F. B. **Mismar** and B. L. Evans, "Partially Blind Handovers for mmWave New Radio Aided by Sub-6 GHz LTE Signaling," Proc. *IEEE Intl. Conf. on Commun. Workshops*, Kansas City, MO, USA, May 2018, pp. 1-5.

[C6] I. da Silva, Y. Wang, F. B. **Mismar** and W. Su, "Event-based performance monitoring for inter-system cell reselection: A SON enabler," International Symposium on Wireless Communication Systems, Paris, France, Oct. 2012, pp. 6-10.

https://github.com/farismismar

https://scholar.google.com/citations?hl=en&user=ztRse_MAAAAJ