Towards Automated RAN Configuration Tuning in Cellular Networks with Causal Learning

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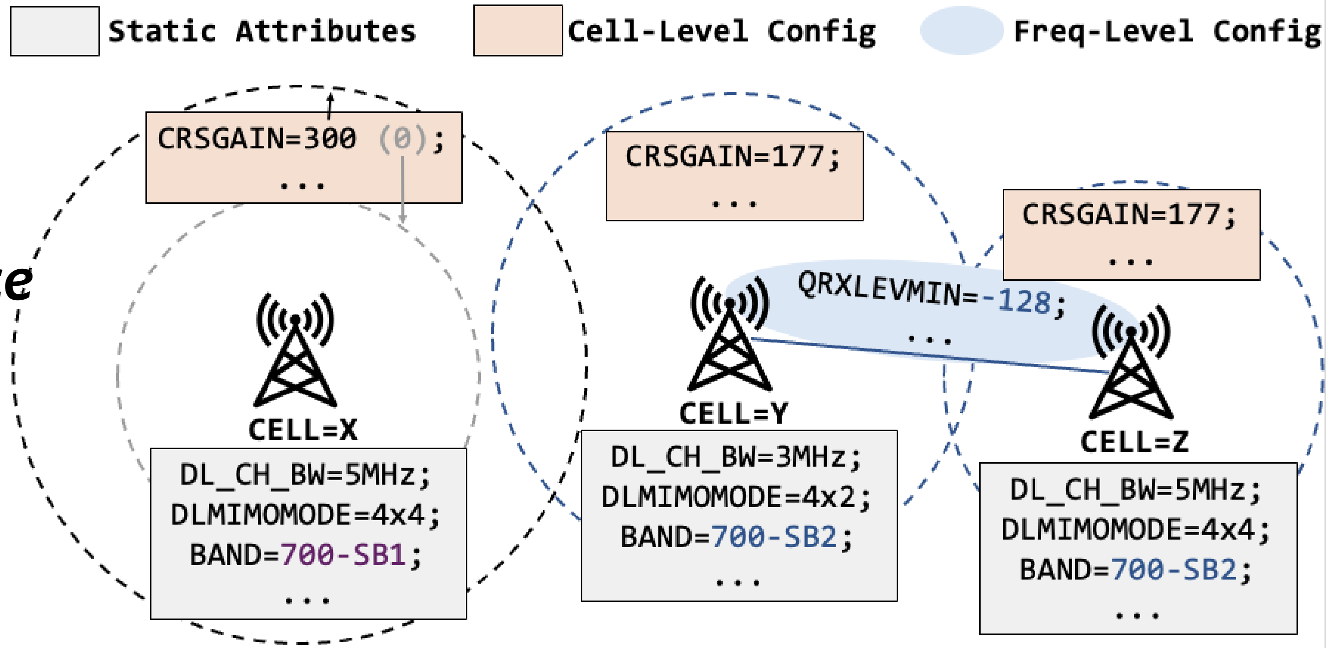
Cellular RAN Configuration Tuning

- ***Configuration tuning drives RAN performance***
  - *Throughput, reliability, energy, and user experience*
- ***Today it is heavily relied on human expertise***
  - *Low risk tolerance on live networks*
  - *Reliability and user experience guaranteed*
- ***Massive scale and high-dimensional space***
  - *Over **1M** cells across the nation*
  - ***Hundreds** of tunable parameters per cell*
- ***Diverse static attributes across cells***
  - *Morphology, Cell Type, Freq-Band, MIMO mode, DLCHBW*
  - *Configs behave differently across the context*



Challenges

- ***Confounding factors obscure the true impact of configuration changes on KPIs***
  - *e.g., traffic demand, mobility patterns, weather*

- ***Sparse Exploration of configuration space***
  - *Some knobs change more often*
  - *Knob values is region specific*
  - *Many knob values remain* ***underexplored***

- ***Configuration parameters are inter-dependent:***
  - *Single knob change behaves differently with multi-knob change*

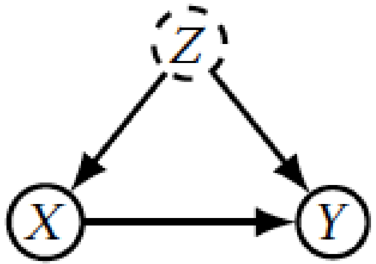
Limitations of Existing Approaches

- ***Manual tuning and verification by RAN engineers***
  - *Dominant approach in practice*
  - *Leans heavily towards conservative/safe settings ⇒ vastly underexplored configuration space*

- ***Correlation based methods (e.g., Auric [SIGCOMM'21], Aurora [IMC'22])***

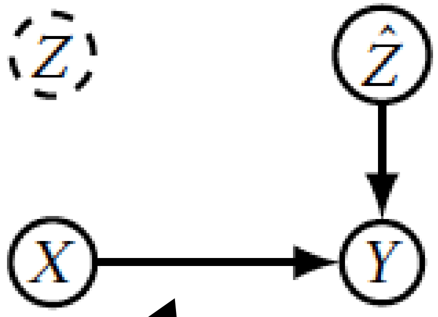
- ***Change based methods (e.g., Iridescence [CoNEXT'25], Chroma [MobiCom'23]***

Limitations of Existing Approaches



- ***Manual tuning and verification by RAN engineers***
- ***Correlation based methods (e.g., Auric [SIGCOMM'21], Aurora [IMC'22])***
  - *Take expert tuning as the gold standard and aims to reuse configurations across similar cells via collaborative filtering or conformity-based recommendations*
  - *Ignores confounder effects, limited interpretability and generalization*
- ***Change based methods (e.g., Iridescence [CoNEXT'25], Chroma [MobiCom'23]***

Limitations of Existing Approaches

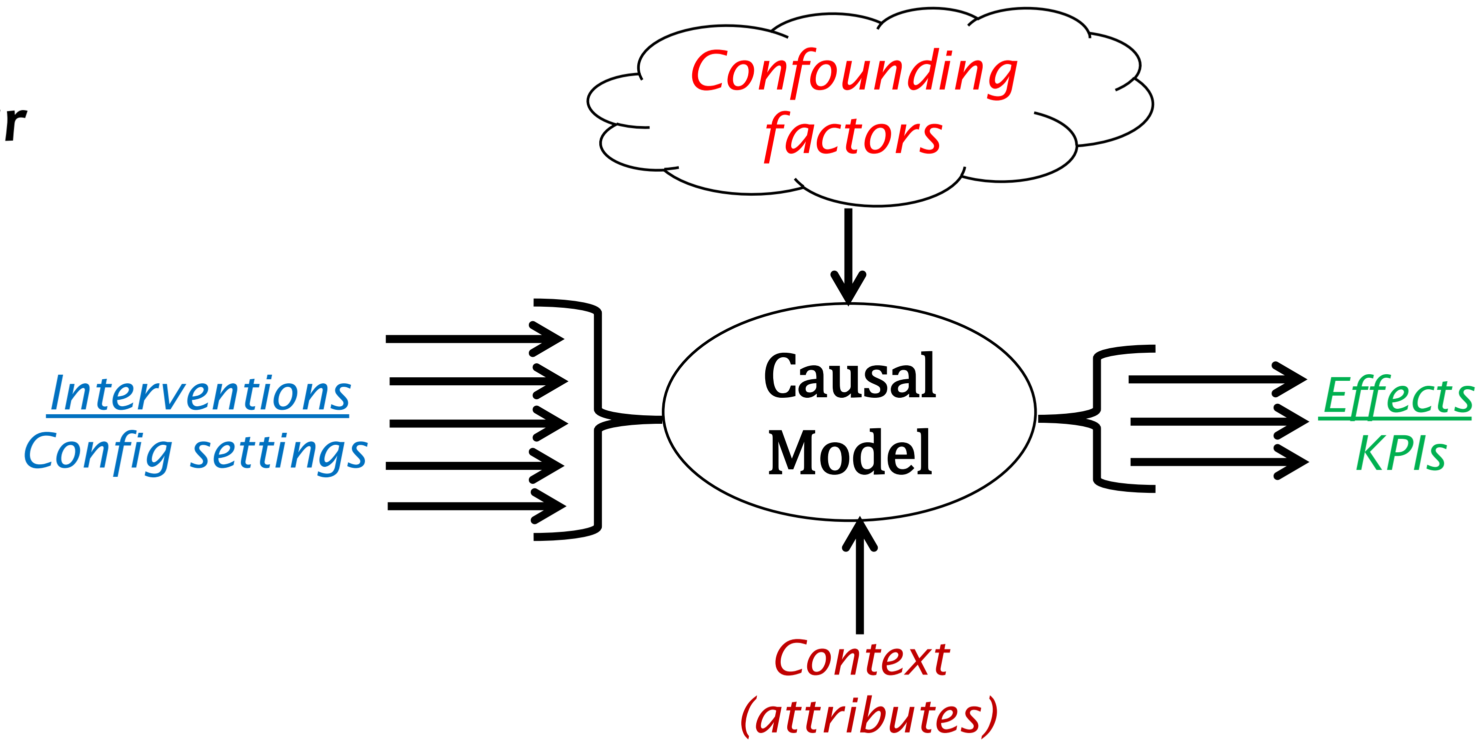


- ***Manual tuning and verification by RAN engineers***
- ***Correlation based methods (e.g., Auric [SIGCOMM'21], Aurora [IMC'22])***
- ***Change based methods (e.g., Chroma [MobiCom'23], Iridescence [CoNEXT'25])***
- *Forecast ΔKPI around the change events*
  - *Very few measured samples for change events*
  - *Affected by concurrent changes in confounding factors*

Our Approach: Causal Learning

- *Introduced for the* ***first time in cellular RAN domain***

- *Offers a* ***principled approach*** *to:*
  - ***learn true & holistic config-KPI relationships***
  - ***Enable counterfactual reasoning (“what-if analysis”)***



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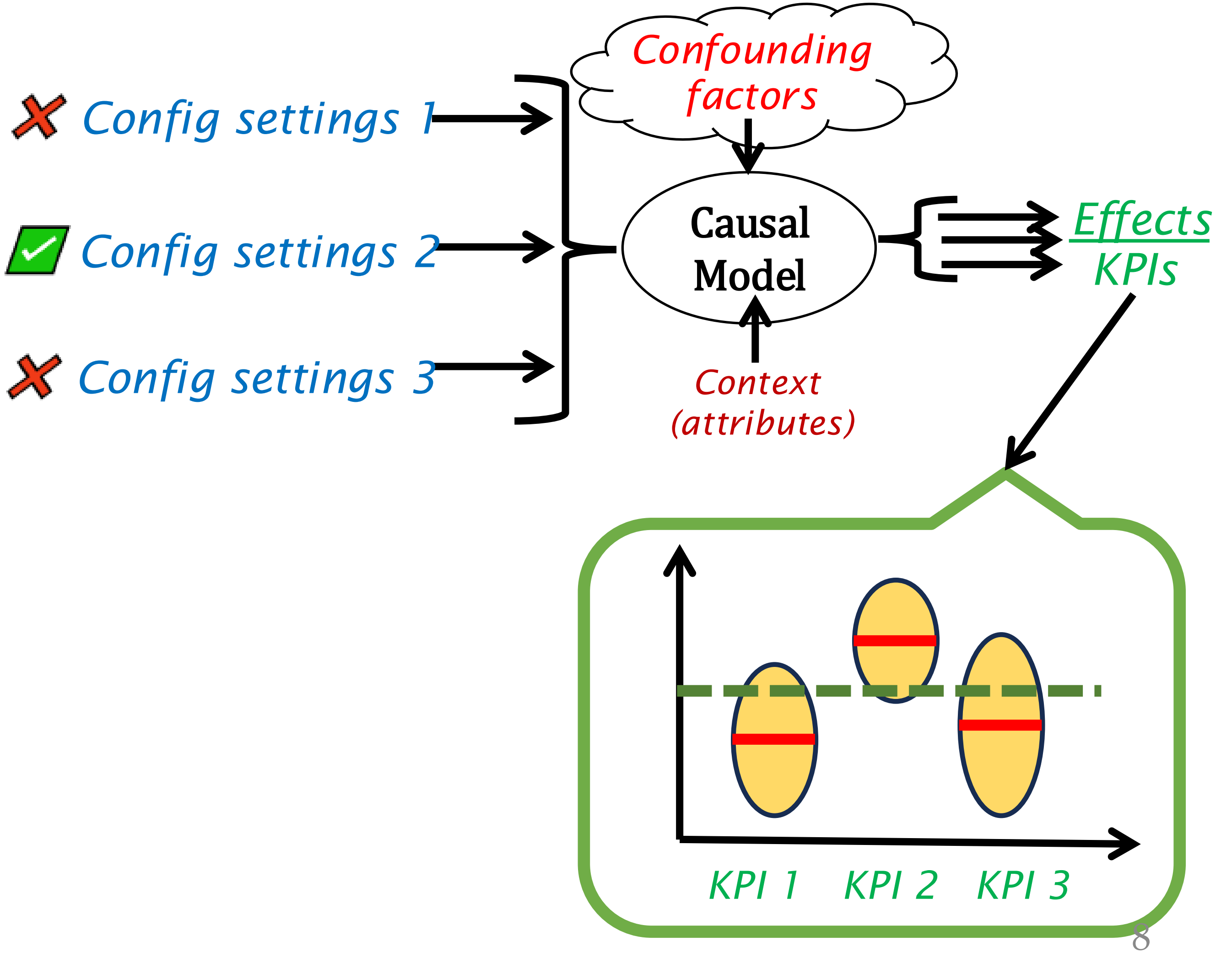
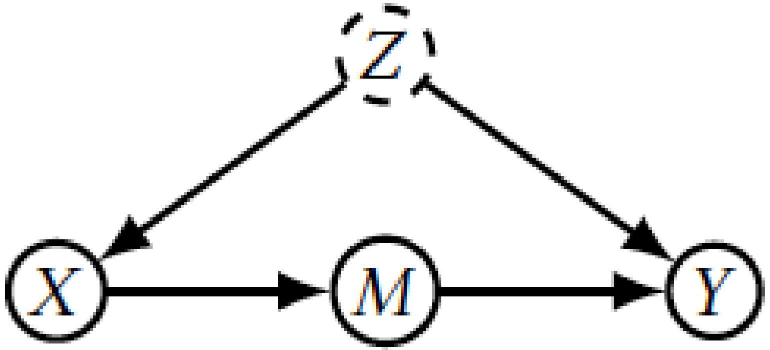
- *Introduced for the **first time in cellular RAN domain***
- *Offers a **principled approach** to:*
  - ***Learn true & holistic config-KPI relationships***
  - ***Enable counterfactual reasoning ("what-if")***
- *By design, it supports confounder handlings, unseen generalization, and reliable recommendations*

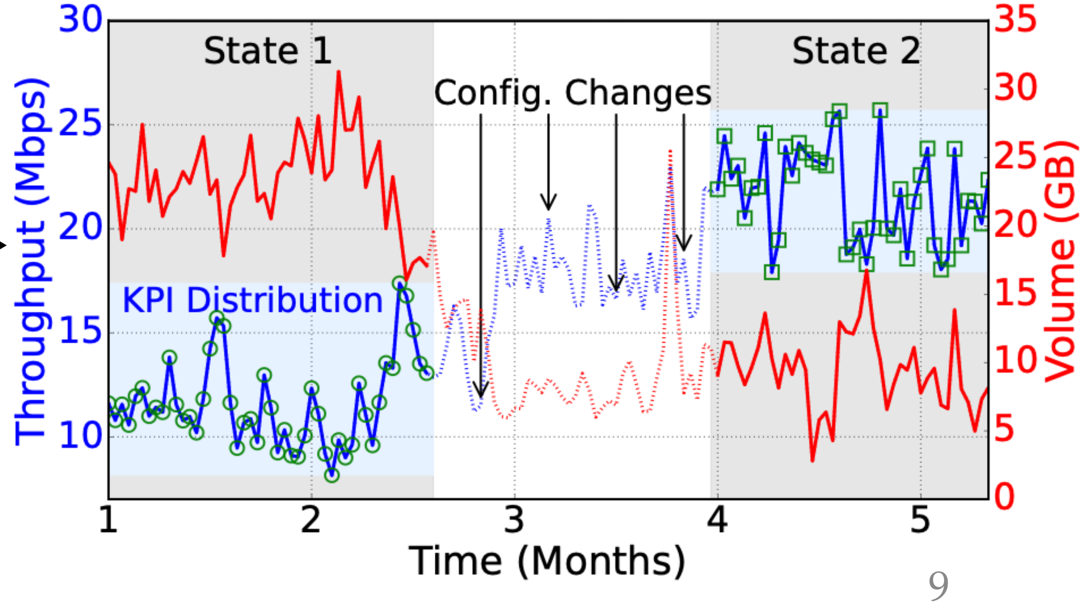


Two Key Design Choices

1. *Given confounders are latent or only partially observed, adopt a* ***front door causal learning*** *method with a* ***mediator M***



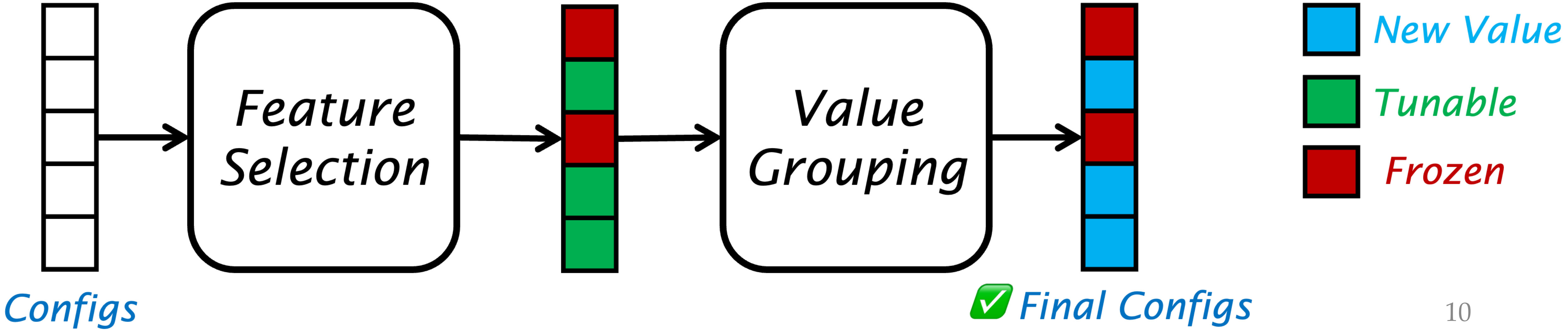
2. *M is KPI distribution across stable configuration periods or* ***configuration snapshots***



Tailored Causal Framework for RAN Configuration Impact Modeling

- ***Feature selection:*** *Which configuration parameters causally affect KPIs?*
  - *Feature-level causal discovery*

- ***Value grouping:*** *What configuration value combinations lead to improved KPI outcomes?*
  - *Value-level causal effect estimation*



Evaluation: Dataset

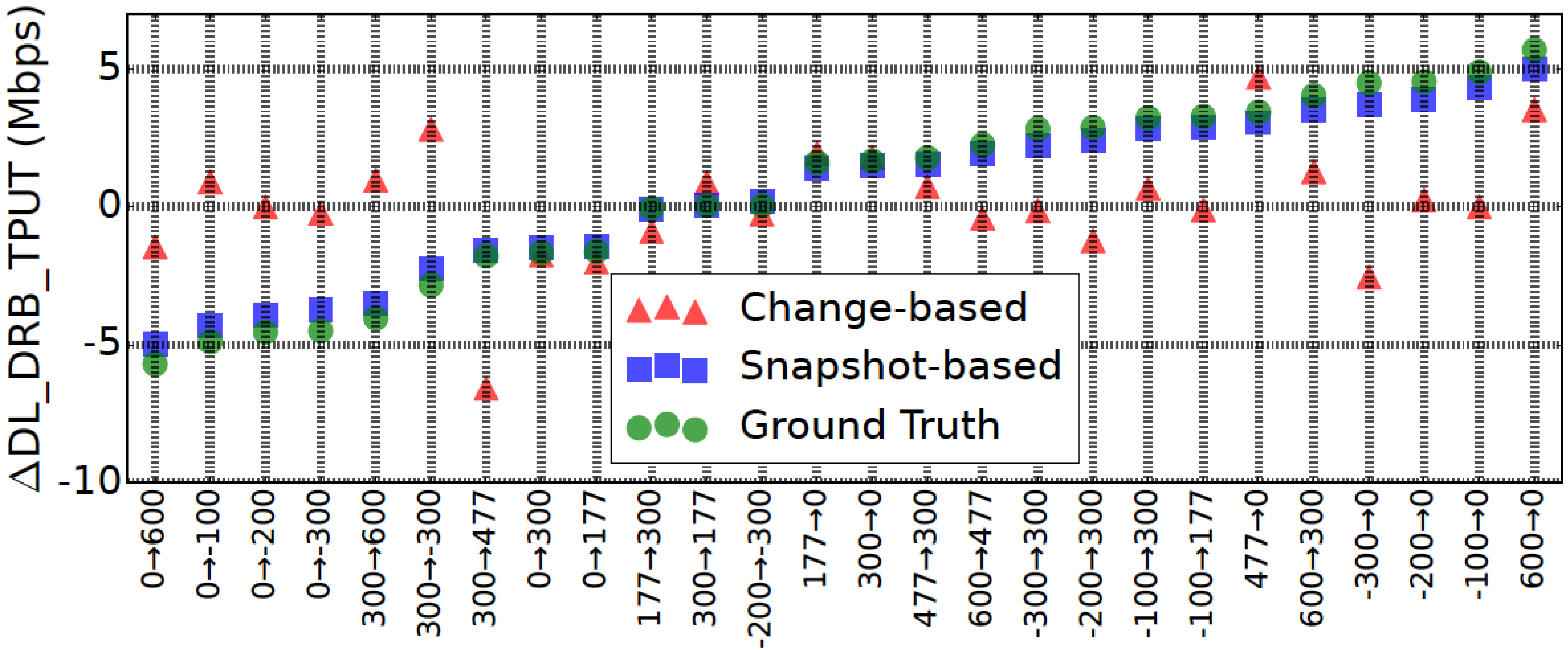
- ***Spans 6 months*** *at daily granularity* ***from an operational cellular network comprising of over 1M cells***
- ***275 distinct config parameters per cell***
- ***7 static attributes***
- *Focus on* ***1 KPI - downlink cell throughput***

Evaluation Methodology

- *Demonstrate the effectiveness and benefits of proposed causal learning approach via multiple experiments and case studies:*
  - *Learned causal weight validation*
  - *Importance of value grouping*
  - *What-if analysis with single or multiple configuration parameters*
  - *Generalization to unseen configuration values*
  - *Transfer learning from data-rich to data-sparse regions*
  - *Computational requirements for training and inference*

What-If Analysis: Impact of Changing Config Parameter(s)

- ***6x improvement in reliability** over state-of-the-art change-based method (Iridesence [CoNEXT'25])*



Changing a single parameter (CRSGAIN)

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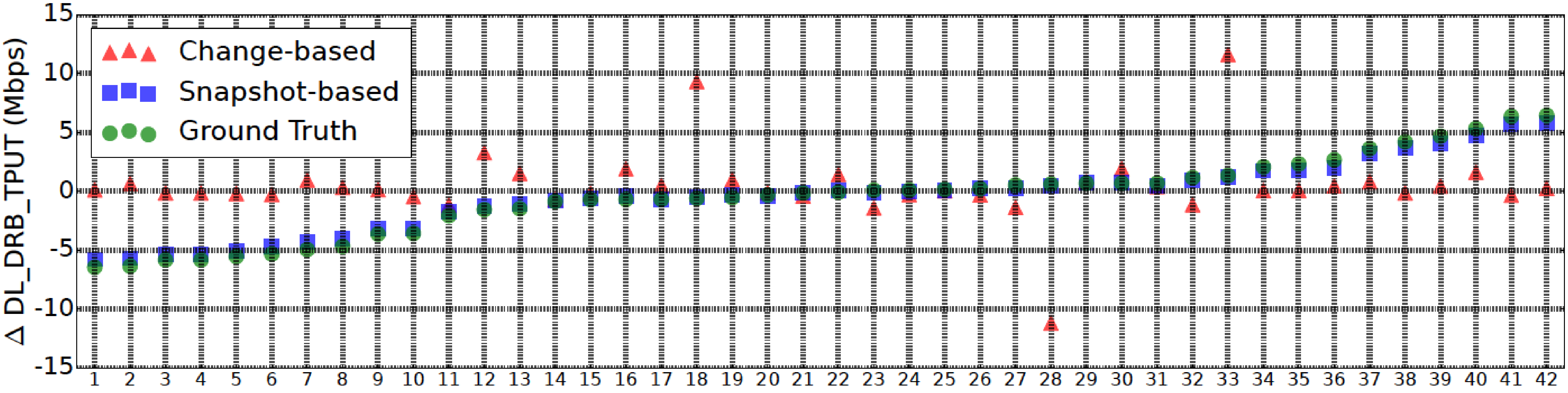

Changing multiple configuration parameters

Summary: Causal Learning makes Config Tuning Automatable

- *The first RAN configuration tuning with* ***front-door causal learning*** *at operational scale*
- ***Feature Selection*** *+* ***Value Grouping*** *under safety and sparsity constraints*
- ***6x*** *performance improvement than SOTA baselines*
- *Building on these results, our extended work has been accepted at* ***SIGCOMM'26***

Q & A ?