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Causal Network Analysis using Markov Chain

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Introduction

When components of a power grid fail, due to a storm, malfunction or cyber-attack, a cascading sequence of subsequent component failures may occur, which may lead to a very large blackouts. Thus, a timely prediction of the components that are most likely to fail next, given a list of a few components that have failed, may enable operators to take mitigating actions (like shutting down sections of the power grid) before a large-scale blackout occurs. The proposed model can simulate a large number of possible cascading failure chains in IEEE 118 bus system as "experience" which can be further used to predict the cascading failure propagation with the highest possibility obtained from the "experience".

Motivations

Blackout Location	Year	People Affected (Millions)	Estimated Loss (Millions)
Turkey	2015	70	700
India	2012	670	6000
Colombia	2007	41	130
Italy	2003	57	1200

Causal Network

A causal network is a directed acyclic graph G = (V, E) to encode causality, where V is the set of nodes representing event types i.e. transmission lines and E is the set of edges between nodes and the weights are the conditional probability of the failure of the transmission lines. For each directed edge, the parent node denotes the cause, and the child node denotes the effect.

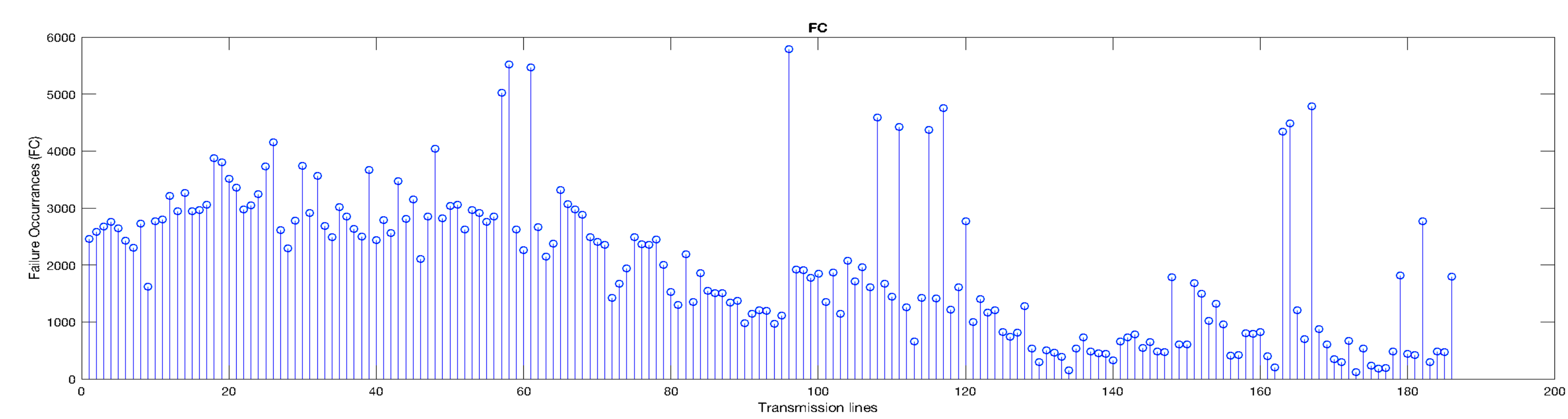
Event Precedence Model (EPM)

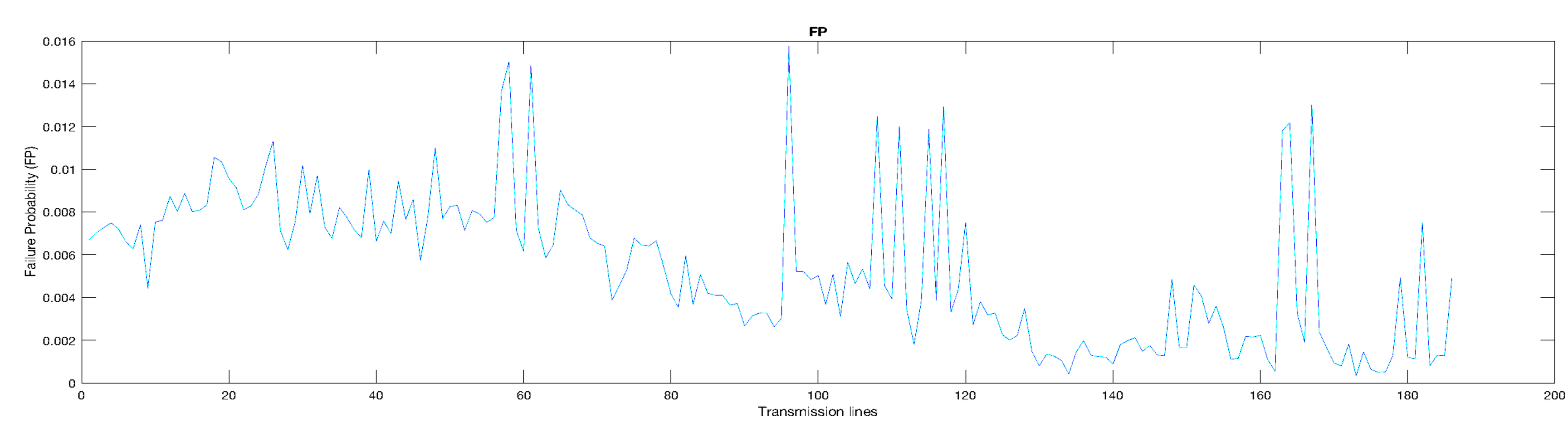
As a required condition for causality, EPM models the temporal precedence relationship between events as a first order Markov chain which is independent of all previous observations except the most recent one, the probability of occurrence of an effect event given past cause events is

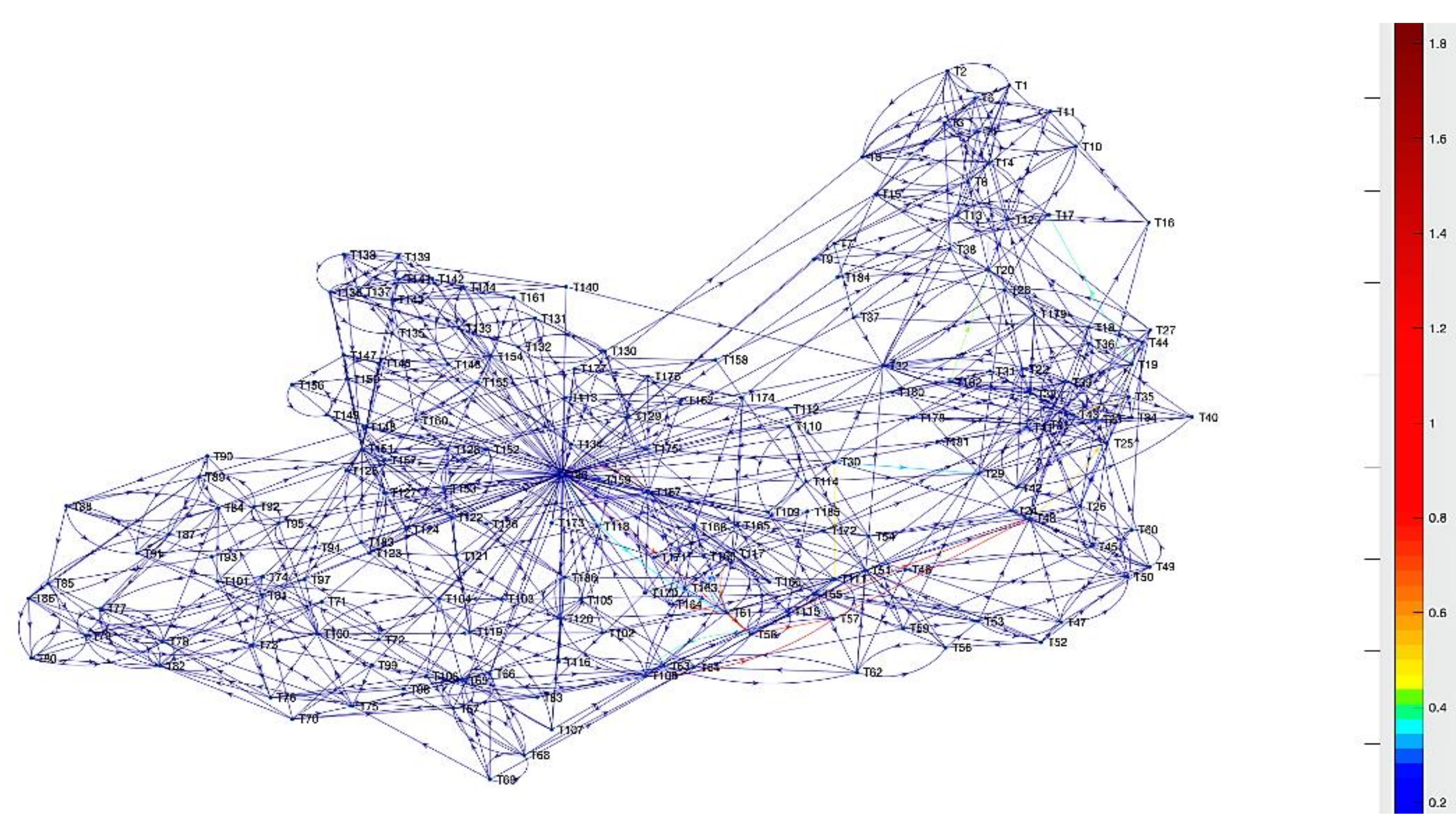
$$w = \sum_{m}^{M} P(A|B_m)P(B_m)\,; [\mathrm{d} > 1]$$

$$s.t.\, P(A|B) = FP(A)_d\,;\; P(B) = FP(B)_{d-1}$$

$FP = \frac{FC}{N}$; FP = Failure Probability, FC = Number of failure occurrence, N = total number of sample space







Stages	Stage 1: Initial Failure	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6
Transmission line	96	61	58	117	108	115
Weight	$w_{1,2}$ 0.0026189	$w_{2,3}$ 0.00033617	$w_{3,4}$ 3.0405e-05	$w_{4,5}$ 1.6194e-06	$w_{5,6}$ 8.7085e-08	
Transmission line	58	117	108	115	57	111
Weight	$w_{1,2}$ 0.0018458	$w_{2,3}$ 0.00013503	$w_{3,4}$ 1.0221e-05	$w_{4,5}$ 9.3403e-06	$w_{5,6}$ 8.6347e-08	
Transmission line	61	58	117	108	115	57
Weight	$w_{1,2}$ 0.0036002	$w_{2,3}$ 0.00040165	$w_{3,4}$ 3.7224e-05	$w_{4,5}$ 3.3476e-06	$w_{5,6}$ 3.4834e-07	

Possible Other Applications

Web-based online systems display the same content for everyone. However, the user experience can be more productive with a dynamic system where content is displayed based on real-time prediction of users' most likely activities, given historical data. One can use the results (i.e. the web pages/links most likely to be visited next) to display the most relevant links, content and advertisements at each step of the user activity.

Summary/Conclusions

1. In this model, the cascade sequence due to the failure of any transmission line can be determined.
2. EPM allows to automatically build a tractable probabilistic graphical model from the events, discovering the existing dependencies among the event types in the event stream. Storing conditional probabilities in the condition nodes facilitates computing the probability of an effect given the occurrence of a cause effect.
3. Event Precedence Network makes the probability model visualized, so that the failure sequence of transmission lines can be easily observed from the graph.

Reference: S. Acharya, B. S. Lee, and P. Hines, "Causal Prediction of Top-k Event Types Over Real-Time Event Streams," The Computer Journal, 2017.