

A Model for Network Resource Allocation Based on Rugged Fitness Landscapes

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The logo for the MITRE Technology Program, featuring a stylized graphic of stacked blocks in yellow, orange, and blue to the left of the text.

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Problem

- **Theoretical underpinnings for wireless communications are largely limited to a single pair of communicating nodes**
- **Results for multi-access networks are limited, particularly in the case of multi-hop networks**
- **Design efforts are often based on ad hoc solutions for which we have little idea about optimality**

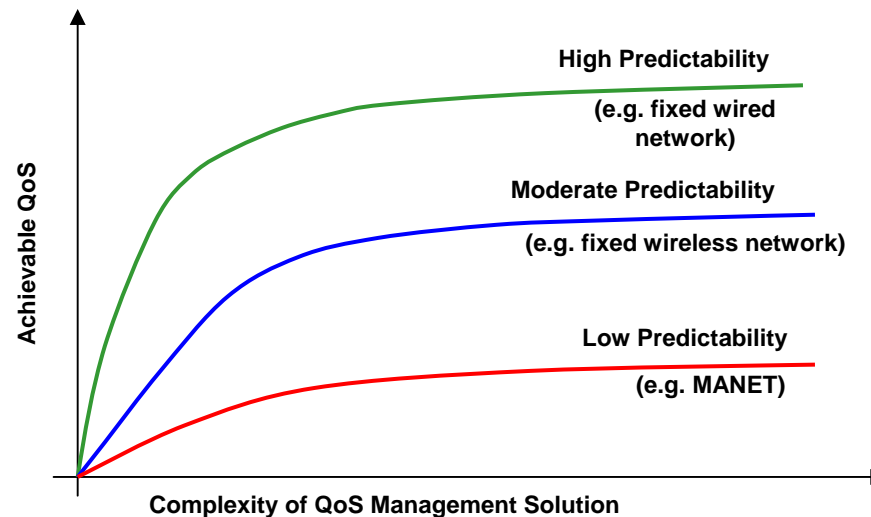
Communication Networks

- **Topology in wireless communication networks is often determined by design (cellular networks, satellite communications) or “mission” objectives (sensor networks, tactical military nets).**
- **We are most interested in achievable Quality of Service**
 - **Without considering delivered service, design goals such as minimizing number of hops (maximizing density of connections), or maximizing network capacity can have negative impacts on network**

Objective

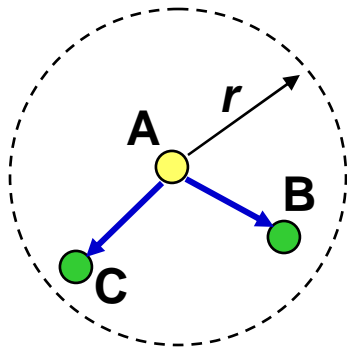
- To characterize networks according to their predictability and study the relationship between predictability and achievable QoS

- Predictability is a measure of the degree to which the state of the network can be reliably observed
- Predictability is also a way to characterize the complexity of a system



Some Assumptions

- Link “quality” is dynamic and quantified as signal-to-noise ratio (γ)
- Physical layer resources, for instance bandwidth (in Hz), can be dynamically allocated to links
- A node transmits omni-directionally and links are established with all nodes within transmit radius r



Kauffman's *NK* Model

- Contention for physical layer resources among links can be captured by the concept of epistasis
- A link is characterized by mean traffic load and mean SNR $(\lambda_i, \bar{\gamma}_i)$
- A link represents a gene and a genotype is characterized by the average bandwidth of each link $(\bar{\beta}_1, \bar{\beta}_2, \dots, \bar{\beta}_N)$
- Strategy is to maximize average capacity as a function of mean BW and mean SNR
 - We get $\sigma_i = \bar{\beta}_i \log(1 + \bar{\gamma}_i)$

What About Epistasis?

- We haven't captured epistasis which results in an *effective BW* less than $\bar{\beta}_i$
- BW will be reduced by some contention factor

$$\varepsilon_i = \int_{B \max}^{\infty} g_B(b) db$$

– Giving us $\hat{\beta}_i = \bar{\beta}_i (1 - \varepsilon_i)$

$$\hat{\sigma}_i = \hat{\beta}_i \log(1 + \bar{\gamma}_i)$$

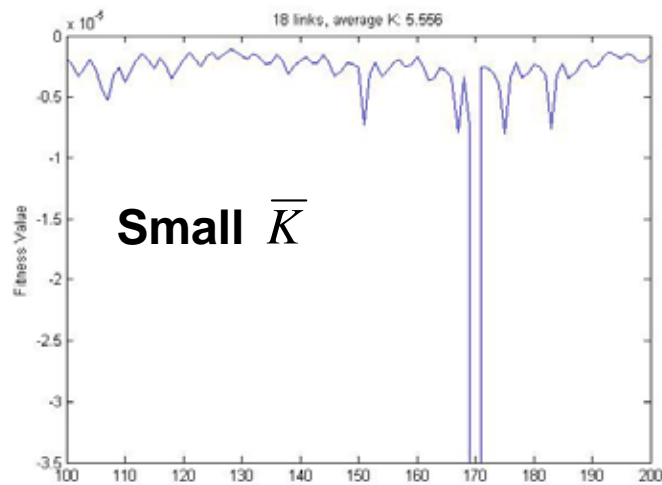
Fitness Function

- We use an M/G/1 queuing model for each link
 - Service time distribution is general
 - Compute mean delay, and then fitness as

$$f_i = -d_i = \frac{\lambda_i}{2\hat{\sigma}_i(\lambda_i - \hat{\sigma}_i)}$$

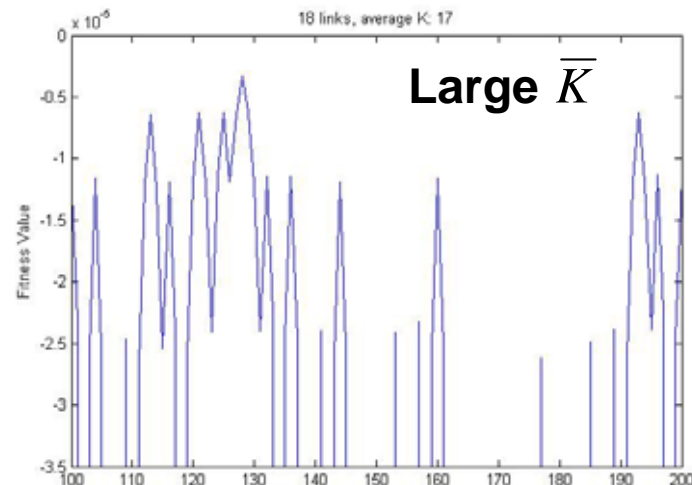
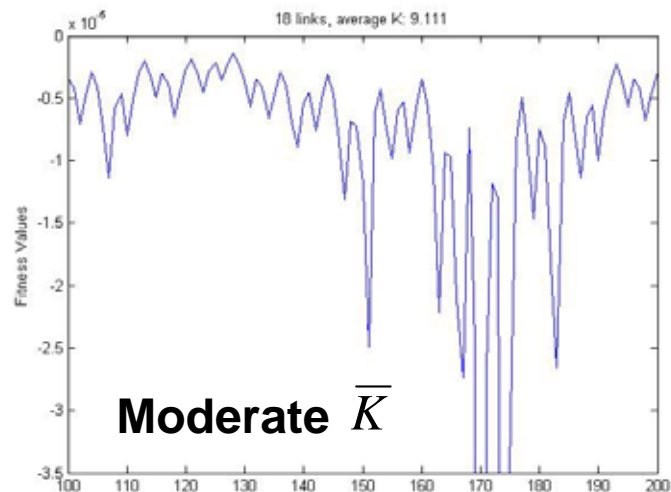
- Network fitness is then computed as average fitness across all links in the network

Sample Landscapes

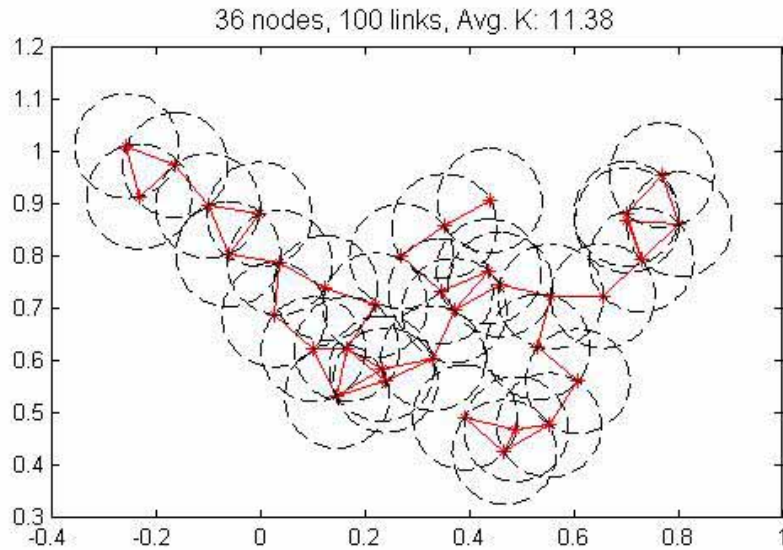


Fitness landscapes for wireless network with varying degrees of *epistasis*.

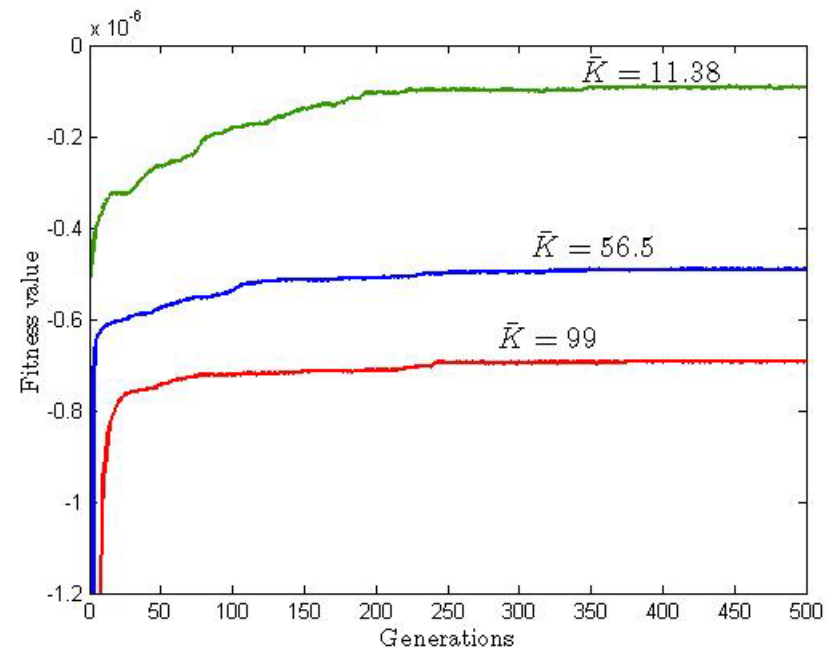
- Fitness function is mean Delay
- Epistasis (\bar{K}) represents contention for wireless resource



Results for Larger Networks



Genetic Algorithm is used to search rugged landscape for optimal resource allocation solution, which maximizes fitness function. →



Note that avg. K is a measure of complexity (inversely proportional to predictability)

Summary

- **These models show promise and may represent a step in the direction of theoretical understanding of communication networks**
- **But they need to be expanded**
 - **Mobility**
 - **Impact of higher layer routing on traffic profiles**