Timing Needs in 2020

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The 2020 Vision

- The NGN Vision
  – A Next Generation Network (NGN) is a packet-based network able to provide Telecommunication Services to users and able to make use of multiple broadband, QoS-enabled transport technologies and in which service-related functions are independent of the underlying transport-related technologies. It enables unfettered access for users to networks and to competing service providers and services of their choice. It supports generalised mobility which will allow consistent and ubiquitous provision of services to users. (ITU-T)
- But do you remember
  – ISDN
  – IN
  – B-ISDN
  – The 'all IP' network

The visionary challenge

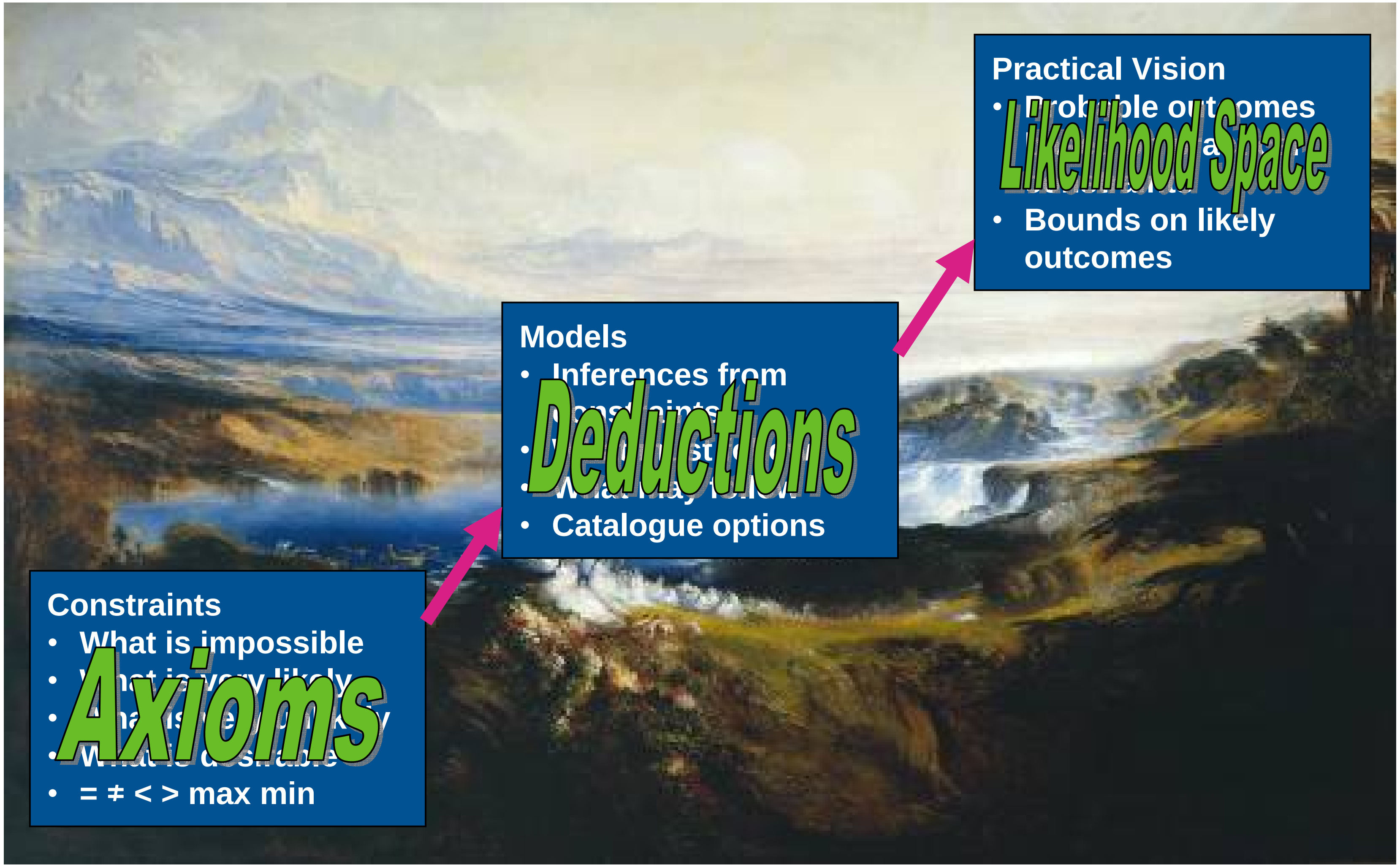
- Being realistic – something commercially, politically, and technically realisable
- Being practical – enduring changes are more often heterogeneous and emergent, and not imposed

Vision without implementation is hallucination
– Benjamin Franklin

The best way to encourage economic growth is to unleash individuals to pursue their own selfish economic interests
– Adam Smith

Everyone imposes his own system as far as his army can reach
– Joseph Stalin

2020 Vision


Constraints
What is impossible
= ≠ < > max min
Axioms
Models
Inferences from
Catalogue options
Deductions
Practical Vision
Bounds on likely outcomes
Likelihood Space

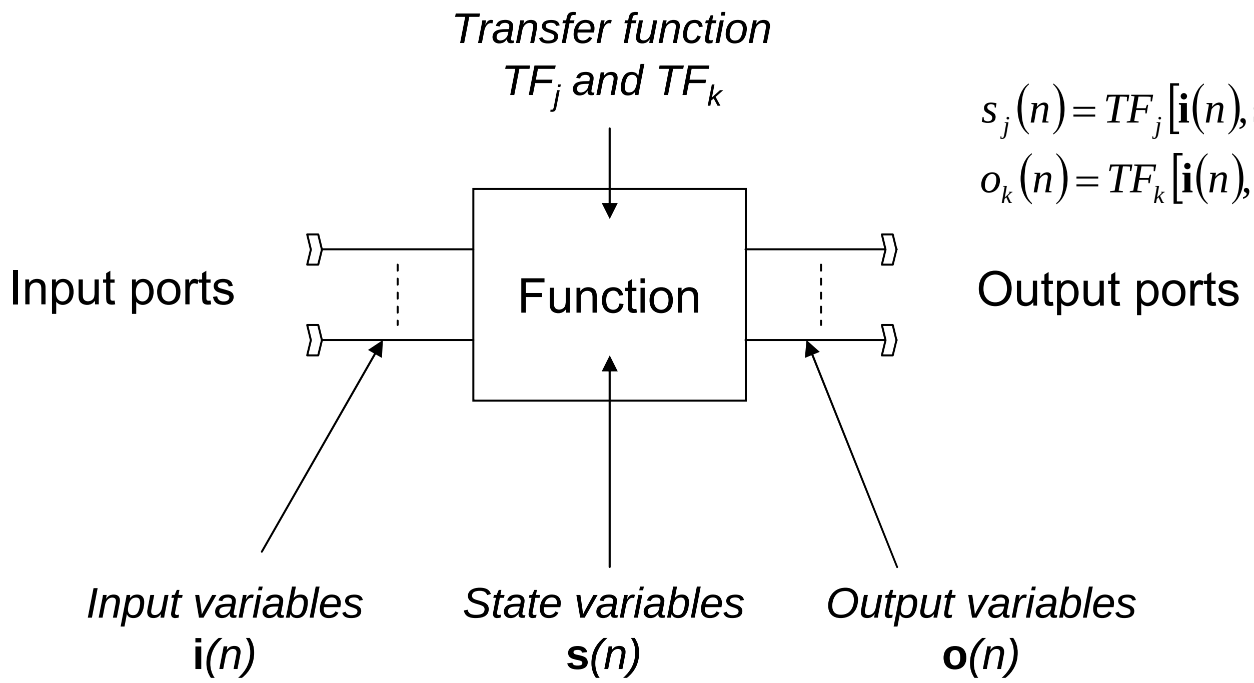
Enduring Constraints

- Nature of Information
  - Enduring scope of telecommunications
  - Telecommunication networks are concerned with the conveyance of ***information*** between senders and receivers when the senders and receivers are separated geographically. (ITU-T G.800)
- Technologies
  - Importance of four underpinning technologies:
    - optical transmission
    - packet switching/routing
    - wireless last mile
    - web services
  - Specifically:
    - Fibre access, DWDM, IP/MPLS, Ethernet, 3GPP, b2c and b2b systems
- Convergence
  - Shift away from product defined markets eg PSTN, data, Internet access, leased lines, etc
  - Emergence of customer markets, residential, SOHO, corporate, etc
- Regulation

Functional Modelling and Specification

- Systems Engineering
  - Telecommunication networks are concerned with the conveyance of ***information***. (ITU-T G.800)
  - Telecommunication networks are ***distributed systems*** (ITU-T G.800)
- ITU-T Unified Functional Architecture
  - ITU-T G.800 deduces user/data plane functions
  - ITU-T G.8080 deduces control plane functions
  - Specify any telecommunications network
    - connectionless and connection oriented
  - Basis for network level architecture specifications
    - Common language for all networks
  - Basis for equipment specifications
    - Precise implementation independent specification
  - Basis for 'northbound' interface to management
    - MTOSI specification in development in TeleManagement Forum

System



$$s_j(n) = TF_j[\mathbf{i}(n), \mathbf{s}(n-1)]$$
$$o_k(n) = TF_k[\mathbf{i}(n), \mathbf{s}(n)]$$

Input Ports

- ***All information of which the system has no prior knowledge***
- ***Shannon Information***

Transfer Function

- ***All information of which the system has prior knowledge***
- ***Algorithmic Information***

Prior Knowledge

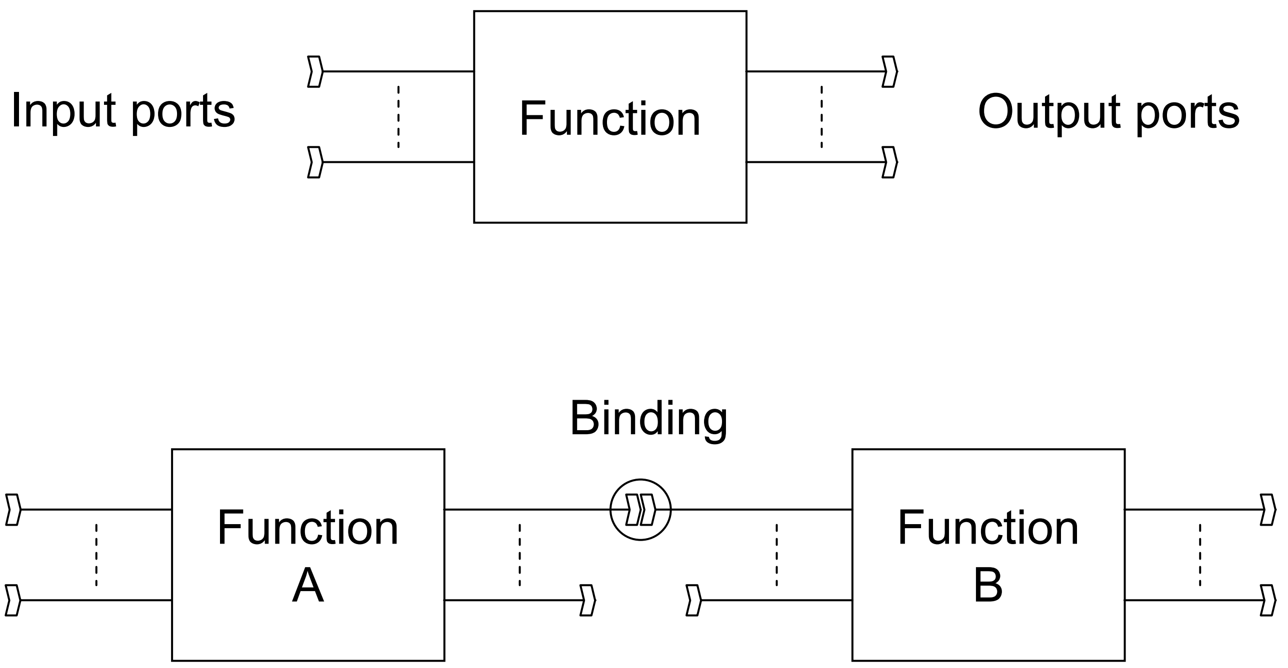
```
    Pi = 3.1415926535 8979323846 2643383279 5028841971 6939937510 5820974944 5923078164
0628620899 8628034825 3421170679 8214808651 3282306647 0938446095 5058223172 5359408128
4811174502 8410270193 8521105559 6446229489 5493038196 4428810975 6659334461 2847564823
3786783165 2712019091 4564856692 3460348610 4543266482 1339360726 0249141273 7245870066
0631558817 4881520920 9628292540 9171536436 7892590360 0113305305 4882046652 1384146951
9415116094 3305727036 5759591953 0921861173 8193261179 3105118548 0744623799 6274956735
1885752724 8912279381 8301194912 9833673362 4406566430 8602139494 6395224737 1907021798
6094370277 0539217176 2931767523 8467481846 7669405132 0005681271 4526356082 7785771342
7577896091 7363717872 1468440901 2249534301 4654958537 1050792279 6892589235 4201995611
2129021960 8640344181 5981362977 4771309960 5187072113 4999999837 2978049951 0597317328
1609631859 5024459455 3469083026 4252230825 3344685035 2619311881 7101000313 7838752886
5875332083 8142061717 7669147303 5982534904 2875546873 1159562863 8823537875 9375195778
1857780532 1712268066 1300192787 6611195909 2164201989 3809525720 1065485863 2788659361
5338182796 8230301952 0353018529 6899577362 2599413891 2497217752 8347913151 5574857242
4541506959 5082953311 6861727855 8890750983 8175463746 4939319255 0604009277 0167113900
9848824012 8583616035 6370766010 4710181942 9555961989 4676783744 9448255379 7747268471
0404753464 6208046684 2590694912 9331367702 8989152104 7521620569 6602405803 8150193511
2533824300 3558764024 7496473263 91419
```

What is the probability distribution for the value of the next digit given knowledge of the previous digits?

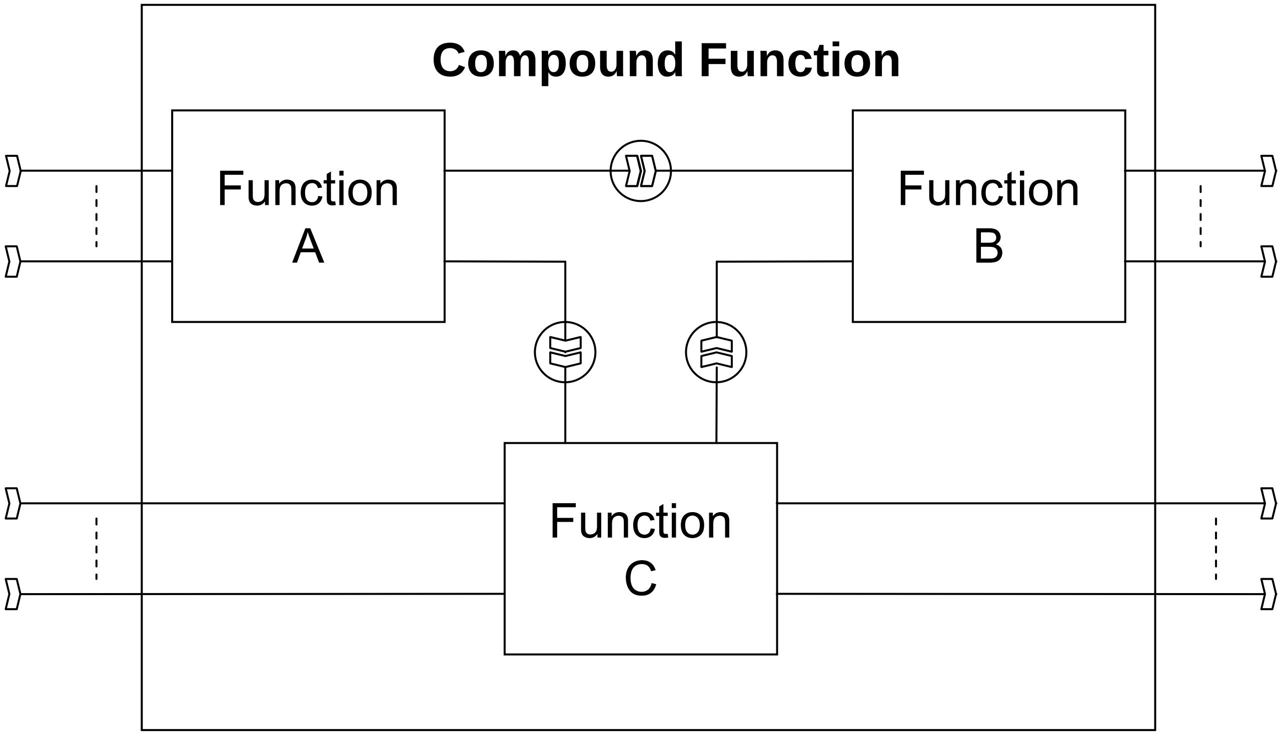
Prior knowledge Digit $\in$ *{0,1,2,3,4,5,6,7,8,9}*

$$\text{Shannon Information} = \sum_{n=0}^{9} p(n)\ln\left(p(n)\right)$$

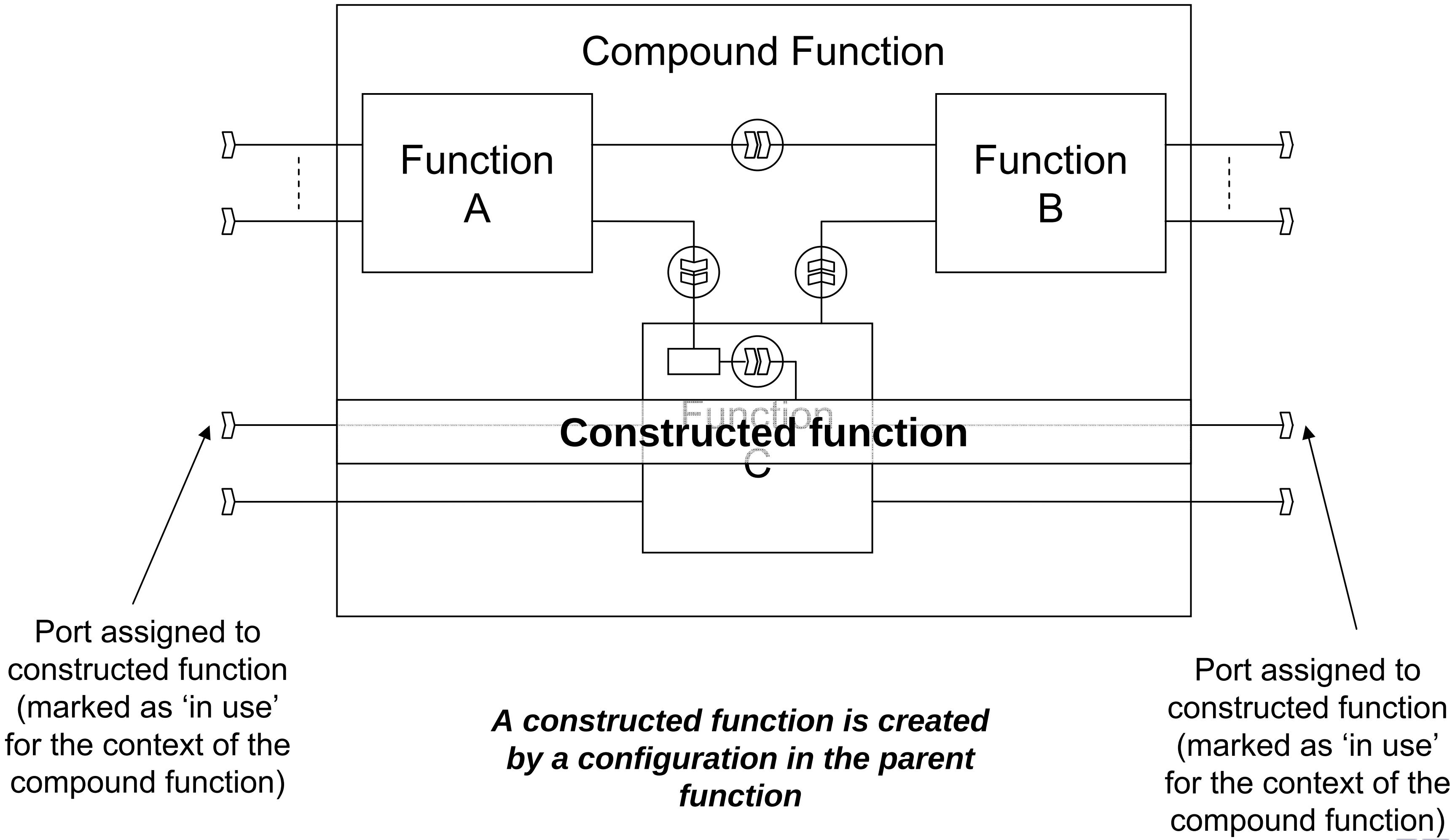
Binding of Systems



Compound System

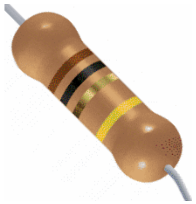


Constructed System

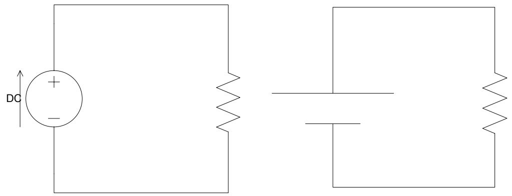


A constructed function is created by a configuration in the parent function

Non Causal Mathematical Modelling



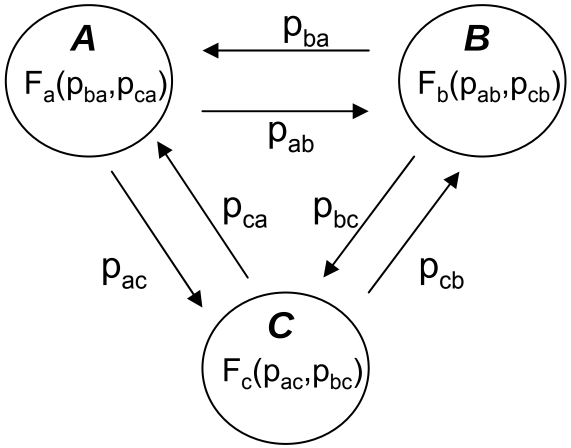
Algebraic model	v = iR
Algorithmic model	v := iR



v = iR	v = iR
v := iR	i := v/R

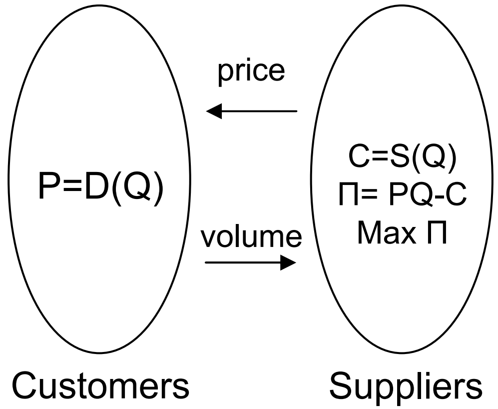
- The algebraic model of the resistor in invariant irrespective of usage but the algorithmic model of the resistor is not
- A standard computer model (numeric and algorithmic) will only calculate one point scenario and with assumed causality

Complex partitioned model



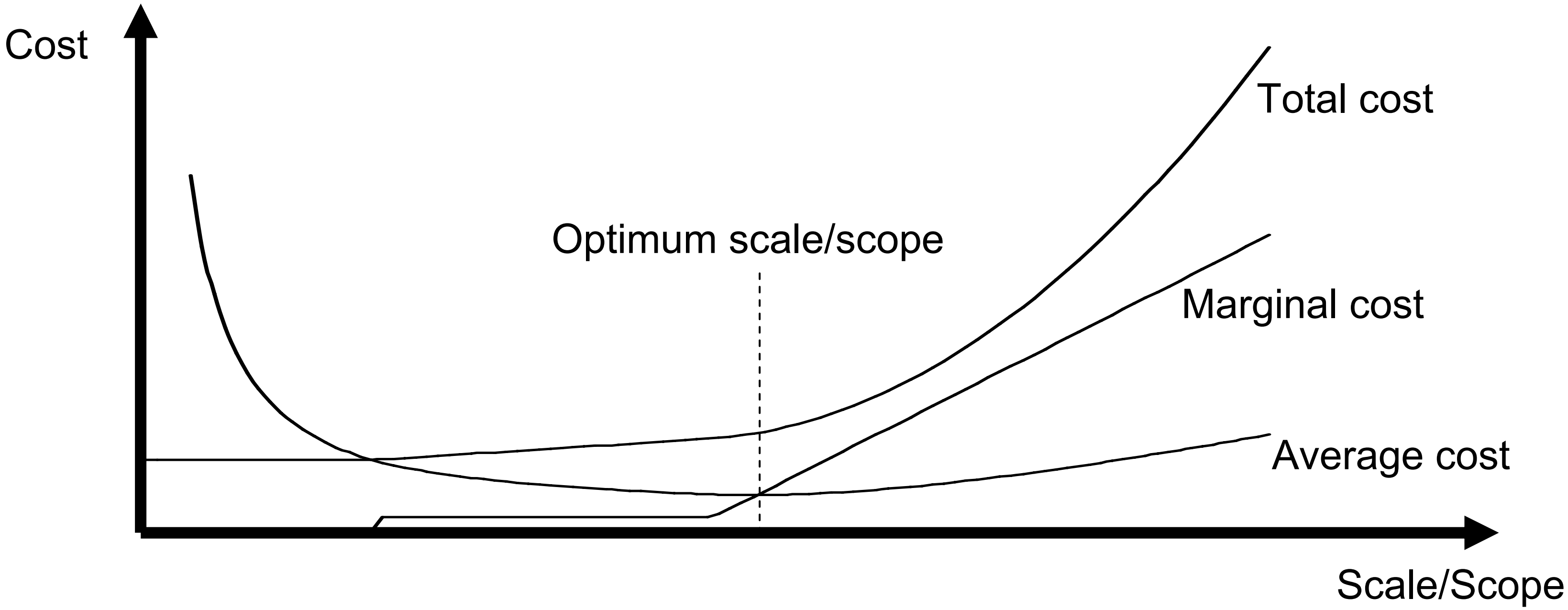
- Effects in other partitions of the model are input parameters and are unknown to the partition
  - Numeric model is in sufficient
- Causality in the overall model cannot be determined within a partition
  - Algorithmic model is insufficient
- Feedback leads to a circularity of causality
  - Dynamic behaviour and/or equilibrium behaviour

Standard economic model



- Overall model is made up from separate 'demand side' and 'supply side' models
- Actual volume and price levels are an equilibrium
- Changing the cost basis produces a complex set of reactions
- Realistic models are more complex with one set of suppliers capable of supplying several groups of customers and vice versa

Non Linear Mathematical Modelling



- Equilibria occur at non linearities
- Optimum scale/scope occurs when the economies of scale/scope balance the diseconomies of scale/scope
- Using assumed linear average costs can never determine optimum scale/scope

NGN Modelling Example - Pricing Solutions

- General rule – pricing points based on volumes with strong effects on marginal cost
  - Other fixed costs recovered against these pricing points
- Price component (1) –
  Physical attachment to the network
  - Includes geographic density deaveraging
- Price component (2) –
  Attachment subscribed bandwidth
  - peak bandwidth
  - rental price point rather than session
- This is the basic pricing model for Broadband Internet access
  - Analysis however applies equally to voice or even video

NGN Cost Structure

Key Costs

	Volume units								
	Customer Density	Geographic size/ Distance	Customer port bandwidth	Service instance Bandwidth/ Duration	# of service provision transactions	# of service instance transactions	# of service assurance transactions	# of billing transactions	Network structure
Duct	●●●	●●●					●		●●●
Fibre	●●●	●●●		●			●		●●●
ISE (optical amp)		●●●		●			●		●●●
Internal i/f nodal equipment			●●●	●●●			●●		●●●
External i/f equipment			●●●	●●●	●●●	●●	●●	●●	●●●
Control equipment					●	●●●	●●	●●●	
Network systems					●●●	●	●●●		●●
Network operations	●●	●●			●●●	●	●●●		●●
Service systems					●●●	●	●●●	●●●	
Service operations					●●●	●	●●●	●●●	
Network development									●●●
Product development									●●●
Overheads									●

Cost Function Under Assumption of Optimal Network Structure

Profit maximisation

$$\max\Pi = \max(PQ - C) \quad \Rightarrow \quad \frac{\partial\Pi}{\partial Q} = 0 \quad \Rightarrow \quad P\frac{(1+\eta)}{\eta} = \frac{\partial C}{\partial Q}$$

Total network cost

$$C_T = C_D(l,n) + C_F(s,l,v,n) + C_N(s,v)$$

$$C_T = C_D(l,n) + C_{Fln}(l,n)C_{Fs}(s)C_{Fv}(v) + C_{Ns}(s)C_{Nv}(v)$$

At optimal structure

$$\frac{\partial C_T}{\partial s} = 0 \quad \Rightarrow \quad \frac{\partial C_{Fs}(s)}{\partial s}C_{Fln}(l,n)C_{Fv}(v) + \frac{\partial C_{Ns}(s)}{\partial s}C_{Nv}(v) = 0$$

Marginal cost of adding a node is

$$\frac{\partial C_T}{\partial n} = \frac{\partial C_{Dln}(l,n)}{\partial n} + \frac{\partial C_{Fln}(l,n)}{\partial n}C_{Fs}(s)C_{Fv}(v) + C_{Fln}(l,n)\frac{\partial C_{Fs}(s)}{\partial s}\frac{\partial s}{\partial n}C_{Fv}(v) + \frac{\partial C_{Ns}(s)}{\partial s}\frac{\partial s}{\partial n}C_{Nv}(v)$$

and at optimal structure

$$\frac{\partial C_T}{\partial n} = \frac{\partial C_{Dln}(l,n)}{\partial n} + \frac{\partial C_{Fln}(l,n)}{\partial n}C_{Fs}(s)C_{Fv}(v)$$

Then marginal cost of bandwidth is

$$\frac{\partial C_T}{\partial v} = C_{Fln}(l,n)\frac{\partial C_{Fs}(s)}{\partial s}\frac{\partial s}{\partial v}C_{Fv}(v) + C_{Fln}(l,n)C_{Fs}(s)\frac{\partial C_{Fv}(v)}{\partial v} + \frac{\partial C_{Ns}(s)}{\partial s}\frac{\partial s}{\partial v}C_{Nv}(v) + C_{Ns}(s)\frac{\partial C_{Nv}(v)}{\partial v}$$

and at optimal structure

$$\frac{\partial C_T}{\partial v} = C_{Fln}(l,n)C_{Fs}(s)\frac{\partial C_{Fv}(v)}{\partial v} + C_{Ns}(s)\frac{\partial C_{Nv}(v)}{\partial v} \quad \approx> \quad \frac{\partial C_T}{\partial v} = C_{Ns}(s)\frac{\partial C_{Nv}(v)}{\partial v}$$

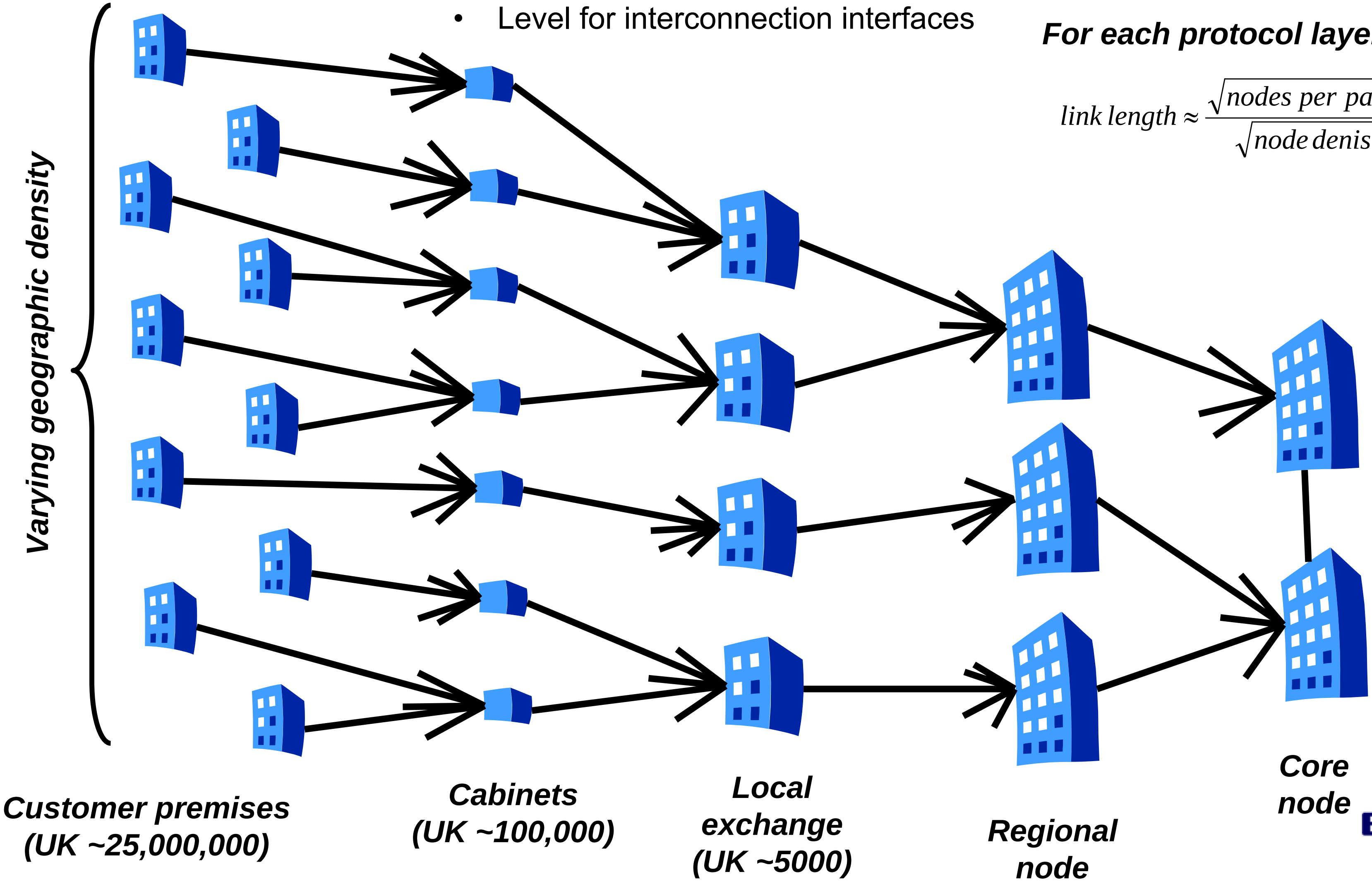
Optimal Network Structure

Key choices

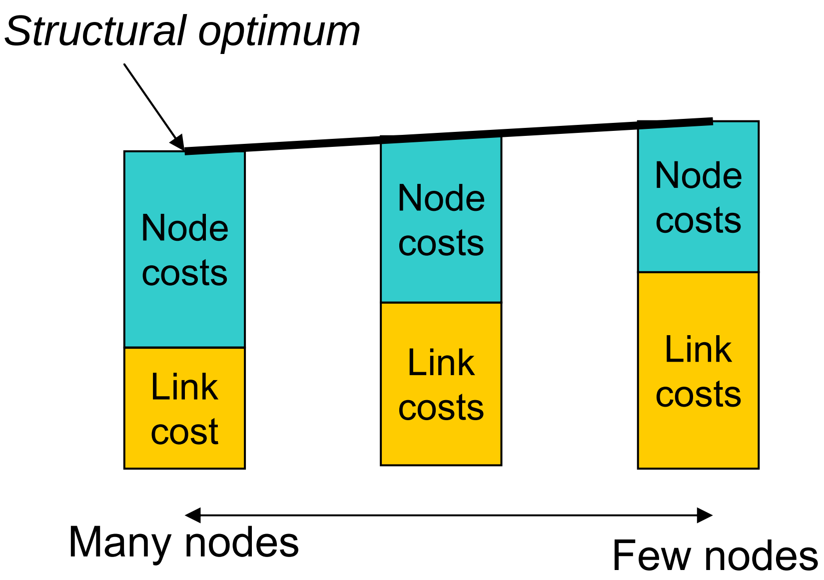
- Protocol/technology at each level
- Number of children per parent
- Level for interconnection interfaces

For each protocol layer

$$link\ length \approx \frac{\sqrt{nodes\ per\ parent}}{\sqrt{node\ denisty}}$$

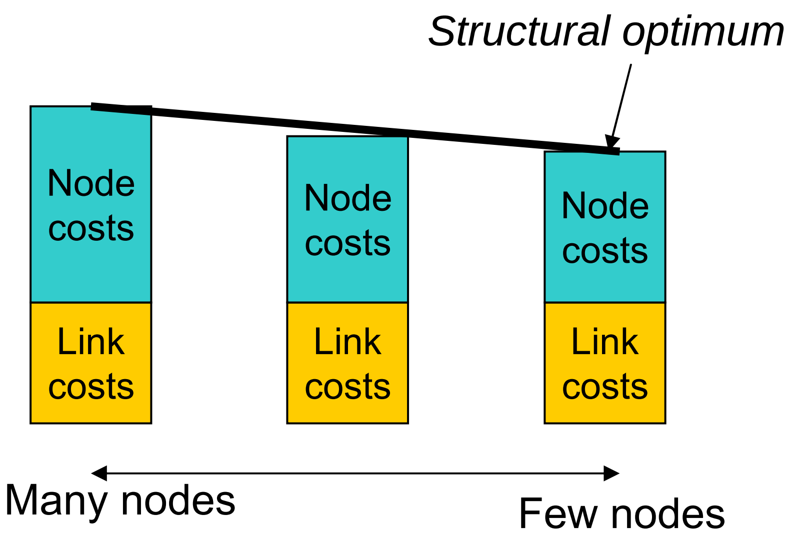


Optimal Structure and Linearity of Trade-offs

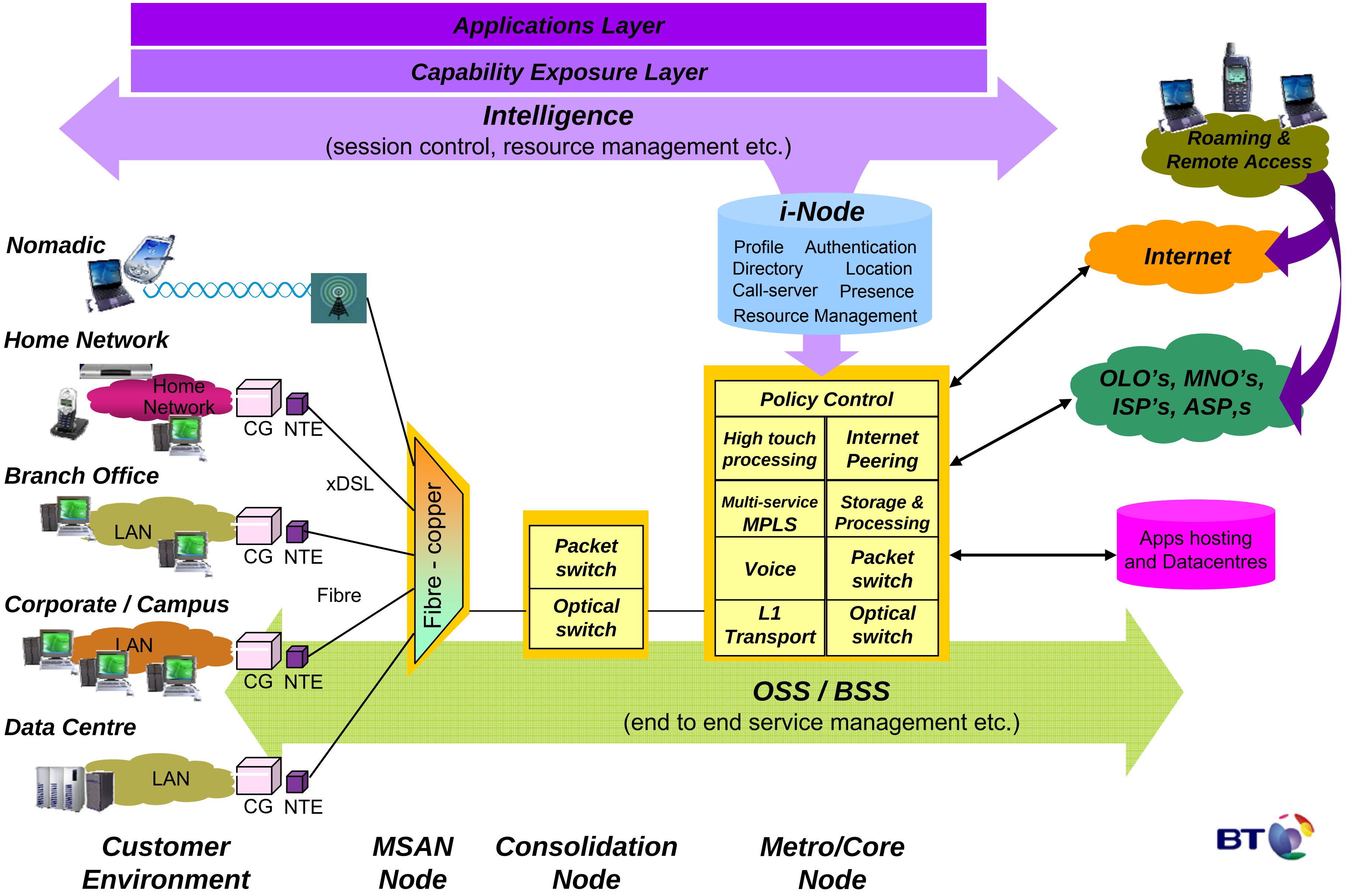


Linear trade-off between cost node costs and link costs

Change to the marginal link costs

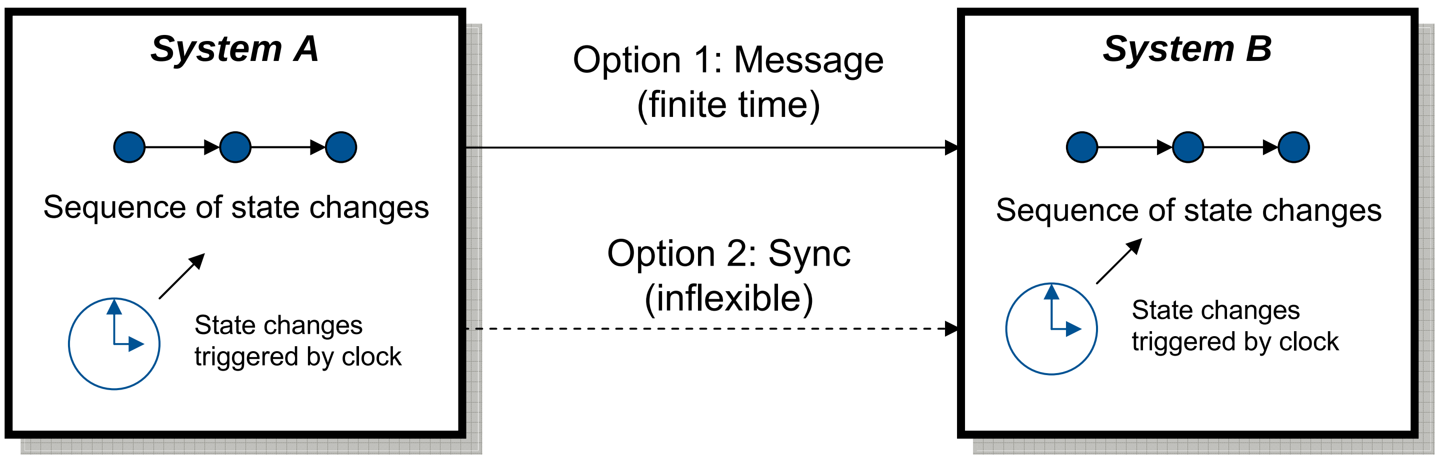


21C High Level Network Architecture



Why Synchronisation?

For deterministic operation of the overall system, System B needs to know the current state of System A



Option 3: Non-deterministic

The overall system can be any two of instantaneous, flexible, deterministic but cannot be all three

Timing Requirements by Application

	Time of day	Absolute delay	Absolute frequency	Low frequency wander	High frequency wander	Jitter
Non-real time (web browsing, download, email, 'instant' messaging, b2c, b2b)	☺	☺				
Packet voice		☻				☺
PSTN voice		☻	☻		☺	☻
Dynamic Mobility	☻	☻	☺	☺	☺	☺
Videophone		☻				☺
Digital TV distribution						☻
Analogue TV distribution					☻	☻
Digital TV contribution	☻					☻

Comparing Frequency and Time Requirements

Estimating time from frequency

$$\phi(t) = \int f(t)dt + C$$

$$\phi_{est}(t) = \phi(t_0) + \sum_{n=0} f(t_0 + n\Delta t)\Delta t$$

This has a fundamental 'bootstrap' problem

Estimating frequency from time

$$f(t) = \frac{d\phi(t)}{dt}$$

$$f_{est}(t) = \frac{\phi(t+\Delta t) - \phi(t-\Delta t)}{2\Delta t} + \varepsilon_f(t)$$

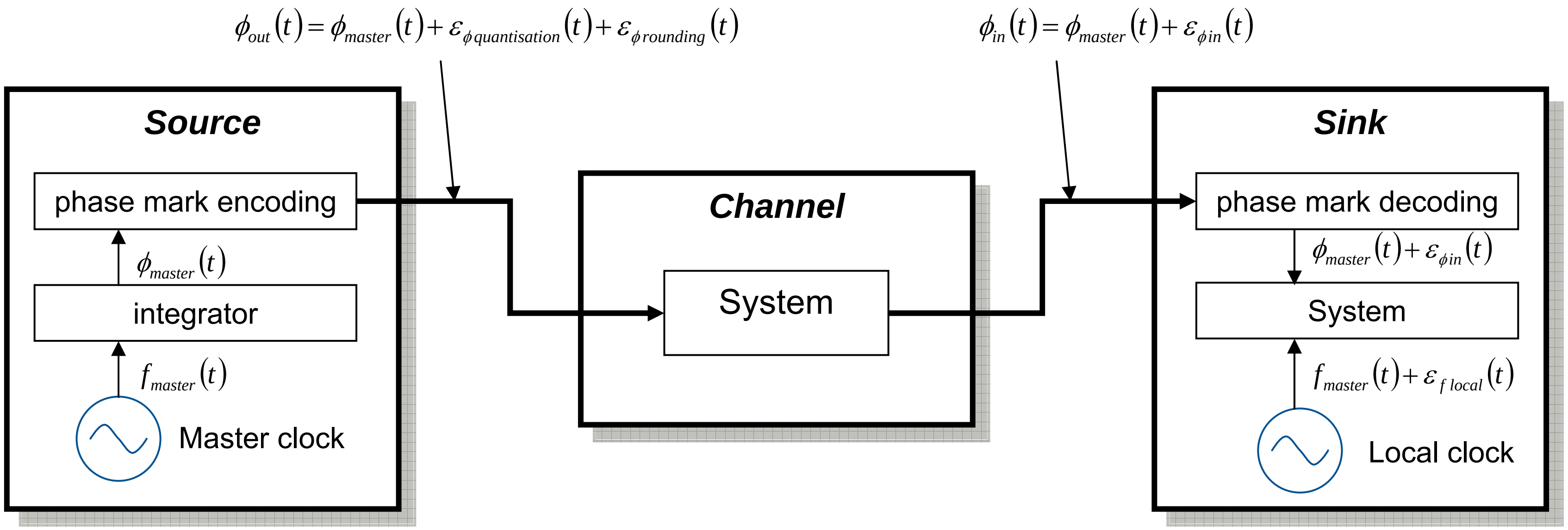
This has a fundamental loss of accuracy

$$\varepsilon_f(t) \approx \frac{1}{2}\Delta t \frac{d^2\phi(t)}{dt^2} + \frac{\varepsilon_\phi(t)}{\Delta t}$$

Whilst large Δt reduces effect of phase error it increases clock difference error and vice versa

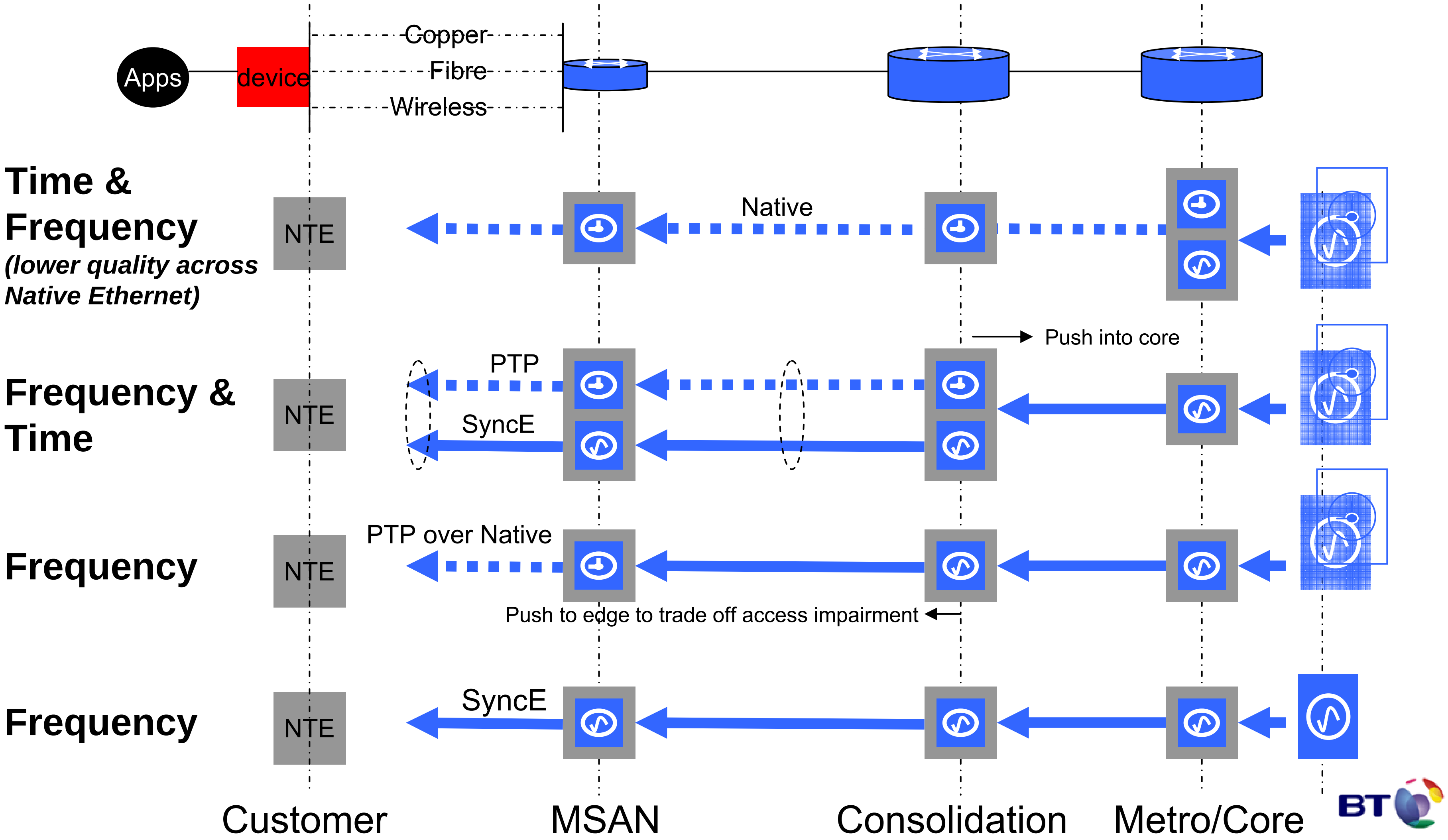
Conclusion – We need to transfer both time and frequency

Frequency Transfer using Time Transfer



- The sink system transfer function is committed at the time of manufacture/deployment and is that which is invariant in any 'adaptive' process. Anything adaptive is a state variable.
- $\varepsilon_{\varphi in}(t)$ and $\varepsilon_{f\,local}(t)$ are analysed and quantified using Shannon's definition of equivocation
  - ***Any correct assumption on the channel system transfer function contributes zero equivocation to $\varepsilon_{\varphi in}(t)$ however any incorrect assumption is likely to contribute large equivocation to $\varepsilon_{\varphi in}(t)$***
  - ***The sink system must take time to reduce the ratio of $\varepsilon_{\varphi in}(t)$ to $\varphi_{master}(t)$ according the degree to which $\varepsilon_{\varphi in}(t)$ is uncorrelated over time***
  - ***$\varepsilon_{f\,local}(t)$ unknown to the sink system normally increases with time (and is the $d^2\varphi/dt^2$ term)***
- Any attempt to reduce the effect of $\varepsilon_{\varphi in}(t)$ increases the effect of $\varepsilon_{f\,local}(t)$ and vice versa

Scenarios Combining Physical & Packet Based Solutions



Conclusions

- Examine the future by cataloguing what is likely to be true and making reasoned deductions from this
- A systems approach to the analysis of telecommunications networks
  - yields very tight constraints on the possible nature of telecommunications networks
- Use of algebraic, non-linear models is key to modelling many complex aspects of telecommunications
  - A lost skill in our industry!
- Timing requirements in 2020 includes both time transfer and frequency transfer
- Packet based transfer of frequency has fundamental limits
  - Needs 'clean' transfer and/or stable local clock