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
- What is very likely
- What is desirable

Axioms

Models
- Inferences from constraints
- What must follow
- What may follow

Deductions
- Catalogue options

Practical Vision
- Probable outcomes
- Bounds on likely outcomes

Likelihood Space

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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

#### Transfer function

$\text{Transfer function } TF_j \text{ and } TF_k$

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

#### 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

#### Input Ports

- Input variables $i(n)$
- State variables $s(n)$
- Output variables $o(n)$

#### Function

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Prior Knowledge

\[ \pi = 3.14159265358979323846 \quad 2643383279 \quad 5028841971 \quad 6939937510 \quad 5820974944 \quad 5923078164 \]

0628620899 8628034825 3421170679 8214808651 3282306647 0938446095 5058223172 5359408128 481174502 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 8640341818 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

533812796 8230301952 0353018529 6899577362 2599413891 2497217752 8347913151 5574857242 4541506959 5082953311 6861727855 8890750983 8175463746 4939319255 0604009277 0167113900

9848824012 8583610035 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 \( \in \{0,1,2,3,4,5,6,7,8,9\} \)**

**Shannon Information**

\[
\sum_{n=0}^{9} p(n) \ln(p(n))
\]
Compound System
A constructed function is created by a configuration in the parent function.
Non Causal Mathematical Modelling

**Complex partitioned model**

- Effects in other partitions of the model are input parameters and are unknown to the partition
- Numeric model is insufficient
- 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

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Algebraic model \( v = iR \)

Algorithmic model \( v := iR \)

- 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

\[
\begin{align*}
&v = iR \\
v := iR
\end{align*}
\]

\[
\begin{align*}
i &= v/R
\end{align*}
\]
Non Linear Mathematical Modelling

- Equilibria occur at nonlinearities
- 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

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<th>Volume units</th>
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<td><strong>Network Structure</strong></td>
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<th>Customer Ovary</th>
<th>Geographic Size/Distance</th>
<th>Port Bandwidth</th>
<th>Customer Duration</th>
<th>Service Bandwidth/Duration</th>
<th># of Service instance transactions</th>
<th># of Service assurance transactions</th>
<th># of Service provision transactions</th>
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Cost Function Under Assumption of Optimal Network Structure

Profit maximisation

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

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

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

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

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

and at optimal structure

\[
\frac{\partial C_T}{\partial v} = C_{Fln}(l, n)C_{Fs}(s)\frac{\partial C_{Fv}(v)}{\partial v} + C_{Ns}(s)\frac{\partial C_{Nv}(v)}{\partial v} \approx \frac{\partial C_T}{\partial v} = C_{Ns}(s)\frac{\partial C_{Nv}(v)}{\partial v}
\]
Optimal Network Structure

Key choices
• Protocol/technology at each level
• Number of children per parent
• Level for interconnection interfaces

For each protocol layer
\[
\text{link length} \approx \sqrt[\text{nodes per parent}]\text{node density}
\]

Varying geographic density

Customer premises (UK ~25,000,000)
Cabinets (UK ~100,000)
Local exchange (UK ~5000)
Regional node
Core node
Optimal Structure and Linearity of Trade-offs

Structural optimum

Many nodes

Few nodes

Linear trade-off between cost node costs and link costs

Change to the marginal link costs

Structural optimum

Many nodes

Few nodes

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Why Synchronisation?

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

Option 1: Message (finite time)
- Sequence of state changes
- State changes triggered by clock

Option 2: Sync (inflexible)
- Sequence of state changes
- State changes triggered by clock

Option 3: Non-deterministic

*The overall system can be any two of instantaneous, flexible, deterministic but cannot be all three*
# Timing Requirements by Application

<table>
<thead>
<tr>
<th>Application</th>
<th>Time of day</th>
<th>Absolute delay</th>
<th>Absolute frequency</th>
<th>Low frequency wander</th>
<th>High frequency wander</th>
<th>Jitter</th>
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<td>(web browsing, download, email, ‘instant’ messaging, b2c, b2b)</td>
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<td>Digital TV contribution</td>
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</table>
Comparing Frequency and Time Requirements

Estimating time from frequency

\[ \phi(t) = \int f(t) dt + C \]
\[ \phi_{\text{ext}}(t) = \phi(t_0) + \sum_{n=0} f(t_0 + n\Delta t) \Delta t \]

This has a fundamental ‘bootstrap’ problem

Estimating frequency from time

\[ f(t) = \frac{d\phi(t)}{dt} \]
\[ f_{\text{est}}(t) = \frac{\phi(t + \Delta t) - \phi(t - \Delta t)}{2\Delta t} + \epsilon_f(t) \]

This has a fundamental loss of accuracy

\[ \epsilon_f(t) \approx \frac{1}{2} \Delta t \frac{d^2 \phi(t)}{dt^2} + \frac{\epsilon_{\phi}(t)}{\Delta t} \]

Whilst large \( \Delta t \) 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

\[
\phi_{\text{out}}(t) = \phi_{\text{master}}(t) + \epsilon_{\text{quantisation}}(t) + \epsilon_{\text{rounding}}(t)
\]

\[
\phi_{\text{in}}(t) = \phi_{\text{master}}(t) + \epsilon_{\text{in}}(t)
\]

- 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.
- \(\epsilon_{\text{in}}(t)\) and \(\epsilon_{f_{\text{local}}}(t)\) are analysed and quantified using Shannon’s definition of equivocation.
  - Any correct assumption on the channel system transfer function contributes zero equivocation to \(\epsilon_{\text{in}}(t)\) however any incorrect assumption is likely to contribute large equivocation to \(\epsilon_{\text{in}}(t)\).
  - The sink system must take time to reduce the ratio of \(\epsilon_{\text{in}}(t)\) to \(\phi_{\text{master}}(t)\) according the degree to which \(\epsilon_{\text{in}}(t)\) is uncorrelated over time.
  - \(\epsilon_{f_{\text{local}}}(t)\) unknown to the sink system normally increases with time (and is the \(d^2\phi/dt^2\) term).
- Any attempt to reduce the effect of \(\epsilon_{\text{in}}(t)\) increases the effect of \(\epsilon_{f_{\text{local}}}(t)\) and vice versa.
Scenarios Combining Physical & Packet Based Solutions

- **Time & Frequency**
  - Lower quality across Native Ethernet

- **Frequency & Time**
  - PTP over Native
  - Push to edge to trade off access impairment

- **Frequency**
  - PTP over Native

- **Frequency**
  - SyncE

---

Customer → MSAN → Consolidation → Metro/Core
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