

# A BRIEF SUMMARY OF SAIN ARCHITECTURAL PRINCIPLES

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*The “vision” for SAIN is to adhere to a few core principles that establish a simple universal network architecture, scalable over at least a range of hectobit per sec sensor networks to petabit per second server networks with exabyte storage. At the same time, the architecture overcomes specific limitations of today’s networks to assure better performance and lower operational cost. Some of these core principles are summarized in this brief paper.*

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## MetaEngineering<sup>1</sup>

The new network architecture uses *meta-engineering* principles where constructs of the architectural paradigm are based on discovering *meta-level* requirements that define engineering problems without regard to implementation issues.<sup>2</sup> A few of SAIN's requirements include:

- Define an architecture that is partitioned so that all information transit uses a single simple universal highly scalable link protocol.

Separately, accept a single preferred access protocol that can be applied to all communication services. Today, it is the Internet Protocol (IP).<sup>3</sup>

- The architecture supports robust admission control of all traffic, guaranteeing timely delivery and eliminating the possibility of contention internal to the network that results in traffic loss (such as packet and cell discard).<sup>4</sup>
- The architecture is *not* based on the premise that unlimited bandwidth will exist everywhere within the network. There will always be parts of the network where congestion cannot be controlled cost-

effectively by overprovisioning<sup>5</sup>.

- The network is connection oriented and synchronously (or, at least, coherently) timed.
- These requirements and more are enabled by the following SAIN architecture premise:

**Separate two prime functions of all networks in a universal underlayer:**

**Connectivity (including routing), and**

**Bandwidth management of each connection and/or aggregation of connections.**

## Preferred Instantiations of the SAIN Architecture

1. The last core principle can be instantiated by defining a separate *underlayer* (Layer 1.5) below Layer 2 of the ISO characterization of networks. (SAIN Layer 1.5 traffic can use both existing physical layer links plus Layer 2 and above links that can emulate a deterministic physical layer.) This fundamental aspect of the new paradigm allows an easy accommodation of both message-based (i.e., packet-based) and continuous flow-based traffic in a common connection-oriented synchronous (coherent) architecture.
2. Time division frames of *cellets* encapsulate all traffic. The size of a cellet for each link is tailored to individual transmission link bandwidth and the range of traffic bandwidths to be supported. Frames Each cellet is implicitly addressed by its location within a time division stream. Each cellet in a frame corresponds to a quantum of bandwidth. Each connection is assigned an integer number of cellets per frame. A cellet's quantum bandwidth that can be assigned is determined by the cellet size for a link and the frame period. For example, a quantum bandwidth of 1,000 bps obtains if the cellet size is 8 bits and the frame period is 8 msec. Any integer multiple of 1,000 bps is an assignable bandwidth up to the link's data rate limit. A frame of 128-bit cellets with a frame period of 1.28  $\mu$ sec results in a quantum

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<sup>1</sup> The term *MetaEngineering* was probably first used in public by Ray Sanders in a lecture at UCLA in 1995. At the time, there were no Internet search reference. A first rudimentary formalization of meta-engineering architectural principles led to founding Tran Telecommunications Corporation, one of the first digital networking companies (in 1969). Although Sanders has not been involved, the term is now being used by others concerning development of abstract formalisms of engineering processes. A recent Google search returned lots of references.

<sup>2</sup> Most networking projects of the past thirty years have started with tacit assumptions that inhibit thinking “outside the box”. The basic meta-engineering work for SAIN was completed in the period 1992-1994 with results that are still simple, timely and promise longevity.

<sup>3</sup> The basic architecture supports other access protocols required in special cases and may be required more broadly in the future.

<sup>4</sup> A corollary of this requirement is that all traffic buffering (as opposed to fast switch buffering) occurs external to the network.

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<sup>5</sup> These currently include most wireless networks, but as flow-based traffic builds, bandwidth requirements of optical links and “last mile” technologies will become an important cost factor in many networks.

## A BRIEF SUMMARY OF SAIN ARCHITECTURAL PRINCIPLES

- bandwidth of 100 megabits per second. There is a lot of flexibility.
- Information processing power need not exist only internal to a network, but is cheap enough to exist now only on the network's periphery<sup>6</sup>. Separating connectivity and bandwidth management from everything else allows unlimited new network capabilities between peer terminations without upgrading to the basic network.
  - There are two types of SAIN nodes, E-Nodes and T-Nodes. E-Nodes are responsible for aggregating all traffic that flows through a network of variable-bandwidth paths. T-Nodes are transit nodes that may include aggregating path traffic into "superpaths" at EX (Exchange) Nodes. Only aggregated traffic appears internal to a network. T-Nodes can be either time division switches based on the SAIN link protocol or existing routers/switches that transport multiple cellets per packet. T-Nodes can scale far beyond routers to include lambda switching. *Cellet switching* results in the increased network scalability both to high and low data rates.
  - Current technology need not be replaced everywhere in the today's network to support the new architecture. However, E-Nodes along with their aggregation multiplexers and concentrators are functionally new. For T-Nodes, existing technology can be adapted to the new paradigm in simple ways without having to depend on all of today's complexity. Longer term development includes building high performance cellet switch nodes. The SAIN paradigm is radically different from what has happened with current practice. SAIN does not implicitly assume that current structures must be the basis of new solution constructs, today's approach that pre-ordains complexity and *ad hoc* solutions.
  - A fundamental part of the SAIN architecture produces a network whose operational characteristics are deterministic. All connections are virtual where each connection's characteristics (bandwidth and latency) can be changed from zero bandwidth to dynamically specified levels while maintaining deterministic end-to-end latency limits. Universal admission control enables strict Class of Service definitions and Quality of Service with deterministic parameters for all traffic.
  - Unlike current packet-switched networks, a path is not synonymous with an end-to-end routed link. A path is a logical entity that can be created as an aggregation of separately routed end-to-end sub-paths. This approach has important security and reliability/availability enhancement ramifications.
  - User packets are resolved only at entry/exit ports of E-Nodes (which are usually simple dynamically-controlled next generation time division multiplexers at server and user terminations). This approach allows time domain aggregation, independent of traffic type. All packet buffering occurs only at entry/exit E-Node multiplex ports. This is critically important in order to make sure that traffic contention is deterministically controlled by each E-Node. Even though routers can be used to emulate Layer 1.5 SAIN switches, there is no packet contention.
  - Unlike conventional circuit switching, there is great flexibility with cellet switching in dynamically controlling cellet locations with a frame. SAIN algorithms cause a stream of cellets to be nearly uniformly spaced within time division frames, minimizing transit node latency. Cellets can be aggregated into packets that pass through conventional packet routers acting as T-Nodes where packet addressing is at a path level and not resolved into individual connections. Maximum node transit latency can be fixed at some desirable level (such as 20  $\mu$ sec)<sup>7</sup>.
  - Resolving cellets into user connections occurs only within E-Nodes. Thus, a control channel is separately (multipli-) routed from user traffic using out-of-band signaling – important to user security, privacy and reliability. Path routing within a network uses a separate control sub-system. Dividing network control in this manner enables using the same architecture in all networks from low-speed wireless and wireline to optical networks with lambda switching.
  - Link capacity utilization is enhanced by two attributes of SAIN. One is deterministic admission control. The other is that packetized flow-based traffic can rely on packet headers being sent once for a packet flow that normally are repeated, in whole or in part, for each packet. Packet data is separately implicitly addressed. This attribute is especially important for enhancing bandwidth efficiency of access networks.
  - New routing strategies can be implemented in the SAIN architecture that simplifies networks. For sure, excellent routing strategies can be implemented that do not require BGP and other complex routing strategies of the Internet.

<sup>6</sup> The Session Initiation Protocol (SIP) architecture is a good example of this trend.

<sup>7</sup> The assigned node latency parameter affects allowable size of packets containing aggregated data for a given link bandwidth.

## Addendum

### Ray Sanders Brief history

1948: Graduated from Stanford University somewhere between Physics and Mathematics, having taken too many music courses to graduate in either department.

1950: Received and MS in Electrical Engineering from Stanford.

1951: Completed all requirements for a PhD (major in Electrical Engineering, minor in Mathematics, except for completion of a dissertation.

1951 to 1958: Key technology roles at Gilfillan Bros. (later called ITT Gilfillan) in electronic countermeasures, electronic missile guidance and large ground radar systems.

1958 to 1967: Key technology roles in founding Space General Corporation (with founders James Fletcher and Frank Lehan) and becoming a pioneer in space communications, focusing on synchronous communication processes and many other things.

1967-1968: Vice President of Engineering at ITT Gilfillan, a department of 1,000 developing advanced radar systems.

1968-1980: Founder and CEO of Tran Telecommunications Corporation, a pioneer digital networking company.

1980-1982: Corporate Vice President of Amdahl Corporation (that had acquired Tran).

1982-1990: Founded as CEO a data base company with the late Edward Glaser, a well-known computer system architect.

1990-1992: Consultant on several communication projects

1992-present: Founder and CEO, CTO of CircuitPath Network Systems Corporation.

### Milestones Leading to SAIN

1953: Ray wrote his first computer program (in hex) for "world's fastest computer", the Scientific Western Automatic Computer (SWAC) at UCLA. The SWAC was a synchronous machine since existing memory (rotating drums and mercury delay lines) forced synchrony. The SWAC used Williams Tube memory that could have been asynchronous clocked, but wasn't at that time. He became fascinated by the relative merits of synchronously clocked to asynchronously clocked (i.e., interrupt-driven) systems involving contention for resources. Even today in computer processor structures, this religious struggle goes on and may never be over.

Late 1950's: AT&T Bell Laboratories formed three study groups to investigate the future of digital technology for the voice network. One of the three groups focused on synchronous networking, but that group did not prevail. Digital technology was destined to save money. T1 for example allowed 24 copper pairs to be replaced by one in central office to central office communications. And besides, "Who needs to synchronize all of the pilot tones in the TD2 radios since voice is the only service that generates profitable revenue."

1960 Ray wrote what is probably the first published paper (in the Proc. IRE, April 1960) denoting energy per bit divided by noise spectral density as the measure of efficiency of various modulation techniques and proved the efficiency advantages of modulation systems that use synchronized carriers with expanded bandwidths.

1960 He was awarded a patent for the world's first Walsh function based modem. Its purpose was to save almost a factor of two in required transmitter power within a spacecraft. (Walsh function communication is the basis of CDMA technology. JPL reinvented the same technology some ten years later and used it for the Mariner spacecraft going to Mars.)

1965 He received the Telemetry Man of the Year Award by the IEEE.

October 28, 1968: First conceived the idea that synchronous communication could simplify switching in large-scale networks.

Thanksgiving, 1968: Ray decided to leave IT&T (rather than take a staff job in New York City) and start a data networking company (Tran Telecommunications) with his two direct reports at IT&T. We raised \$800,000 (equivalent to about \$4,000,000 in 2007 dollars) in three weeks and in the bank in six after writing an 8-page business plan that basically said "give us the money and we will figure out what we are going to do". The underlying business assumptions were that even though AT&T was still committed to using digital technology only to save money within the analog network. T1, T2, T3 and T4 had been defined and used for interoffice but the multiplexers used plesiochronous link-by-link clocking, We postulated that T1 would become a national standard and the national network would be synchronized. (This happened even sooner than we expected.)

1969: AT&T released to manufacturing by Western Electric a T1 "data set" (modem) called the 306. It could only be used over T1 facilities which at that time were limited to 50 mile links, but it represented a chance for us. Unfortunately, this was the first time AT&T had built a modem that could not be clocked by subscriber equipment. We asked informally at a meeting with three

## A BRIEF SUMMARY OF SAIN ARCHITECTURAL PRINCIPLES

people at Bell Laboratories that AT&T change the equipment so we could use it to build synchronous networks. After review, we were told that it was too late to make the change. A few months later, we made a formal petition to AT&T management that the change be made. We were then subsequently invited put on a presentation again at the Labs. This time, we walked in and found ourselves talking to a room full of about 30 people. We were told later that many in the room had participated in the late '50's study group advocating synchronizing the network. A few months after that we did receive a letter telling us that the data set would be changed. Even though we were never able to convince any business to put up a T1-based network with 50-mile links, we found out about ten years later that the meeting was probably the catalyst that resulted in AT&T deciding to synchronize the voice network rather than using plesiochronous link-by-link clocking.

1971: We delivered the first synchronously clocked data network (private line) to the State of California state universities. It contained 20 nodes scattered throughout the state using 9,600 bps modems.

1972: Based on the success of the California network, we were awarded a sole source contract by Bell Canada and the Trans Canada Telephone System (now called the Stentor Alliance), to build the nationwide data network to provide private line digital service for all data rates between 300 bps and 64 Kbps. This network, called the DataRoute was inaugurated in early 1973 and was built out to some 250 nodes over the ensuing years. This network was synchronously clocked, initially using only \$5.00 crystals, but later was tied to Cesium clocks as by then had become standardized for the telephone network<sup>8 9</sup>.

1974: Tran was awarded a contract by Pacific Bell to build the statewide switched data network. It was based on Tran's "Pacuit" switches which combined both circuit switched and packet switched data traffic into a network fabric. The protocol was proprietary and was replaced by the then only available international standard X.25 switches designed manufactured by

Tran. Tran became a major supplier of X.25 networks in the international market and AT&T in addition to Pacific Bell became a significant customer.

1976 to 1982: We became major proponents of X.25, not because it was a very good protocol, but it was the only one that had become an international standard at the time. It was not prudent to continue trying to pioneer the "Pacuit" approach even though we had a strong patent position in non-integer time division multiplexing.

1982-1990: Ray left the communication business to try a second life in the database business. (Big mistake!)

1992: Being unaware of any details of ATM until being stunned by what the ITU had come up with as a digital network architecture, a small group of us decided that ATM would become another also-ran architectural and that we should start thinking about an alternative to both all asynchronously switched networks. Even though ATM was at least connection oriented and was tailored to use isochronous transmission facilities, it still shared the same complexities of IP-based asynchronous switching and its difficulties dealing with contention of bursty traffic.

1992 – present: Although it has been a long journey, it has been an exciting one discovering simple ways to overcome complex problems in networking. It is now timely to find collaborators both in academia and industry to work on making SAIN and open standard that can become the basis of FIND. The SAIN architecture is radical, but its instantiation does not need endless inventing.

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<sup>8</sup> Sol Golomb, a well-known professor at USC, and Ray have collaborated on projects for well of 40 years. Sol came up with the notion of King of the Mountain master clock node synchronization. We filed for a patent on how to implement such an approach only to find that AT&T already had a patent issued in 1958 that was a better instantiation than ours. We licensed their patent rather than re-invent something else.

<sup>9</sup> Even so, a Stratum 1 Cesium clock to which all other clocks in a network are slaved only provides synchronous timing within the network. Interconnected networks still use plesiochronous (SONET) links to match sub-multiplexed connections. This still exists even though we now enjoy UTC universal time that is based on the time average of many Cesium clocks. It is accurate any place in the world to a degree that makes other simple means of overcome jitter practical in inter-network synchronization.