Design and construction of a telecommunication network for remote Pacific atolls

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A telecommunication network designed for, and installed in, Tokelau during the period 1995 to 1997 is described. The installed network consists of three satellite earth stations, PABX's and underground local access cabling. Back-up power is provided by dedicated engine-alternators. Equipment environment control is accomplished using passive STAR cooling equipment. Logistics and infrastructure are discussed.

Keywords: *Tokelau – telecommunication network – local access network – telephone exchange – satellite communication – cooling equipment*

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1. Introduction

Tokelau is New Zealand's sole remaining dependency outside of Antarctica. It consists of three remote and very low-lying coral atolls, Fakaofo, Nukunonu and Atafu, roughly 80 kilometres apart in a straight line, and supports a total population of some 1400 people. Situated nine degrees south of the Equator, Tokelau lies some 480 kilometres north of its nearest neighbour, Western Samoa. The only way to get to Tokelau is by the five-weekly supply ship from Western Samoa. There is no air service.

Prior to the installation of the present network, telecommunications had been restricted to infrequent use of single-channel high frequency single-sideband (HF SSB) radio links between the atolls and to the Tokelau Apia Liaison Office in Western Samoa. Since 1994, scheduled point-to-point and multi-point simplex satellite communications between the atolls, the University of the South Pacific and Wellington Polytechnic using PEACESAT had also been possible. The PEACESAT system allowed a limited number of phone patches to be set up via Wellington and the transmission of poor quality facsimiles. Both systems suffered from continual outages due to equipment failures and, for the former, poor radio propagation, and were thus unreliable.

An attempt to provide a telephone service in the 1980s using prototype frequency-agile HF SSB radio equipment ended in failure after the manufacturer of the radio equipment discontinued development and support of the equipment and a cyclone washed away the station in Fakaofo.

In 1994 a joint project to provide commercial quality telecommunications was initiated between Tokelau, the New Zealand Official Development Agency, the United Nations Development Programme (UNDP) and the International Telecommunication Union (ITU). Tokelau and New Zealand provided equal shares towards the capital cost, amounting to NZ$3.4 million, and UNDP and ITU provided a further US$460,000 towards technical assistance.

Impetus to provide reliable telecommunications was provided by recent moves by Tokelau towards self-determination, and the project got under way in August 1995, when the present author took up the position of Project Manager, initially based in Apia, to head the project. Due to the lack of communications and difficult transport it was impracticable to establish a project office in Tokelau until the construction work began in July 1996. The network was cut-over for national toll traffic in March 1997 and international traffic in April 1997. In doing so, Tokelau became one of the last countries, and possibly *the* last country, in the world to introduce a telephone service.

2. Choice of system

Earlier investigations[1] had established that terrestrial communication between the atolls was not feasible, and had concluded that satellite communications offered the only possible means to provide commercial quality telecommunications between the atolls and to the rest of the world. It had been proposed that the Telstra (Telecommunication Corporation of Australia) analogue PACT-Net service be used, a DAMA (Demand Assigned Multiple Access) system already in use throughout the Pacific region. Demand Assigned Multiple Access service is

particularly suited to small, sparse networks, such as Tokelau's, as any circuit can be routed to any destination. This minimises network requirements, although at the cost of increased equipment complexity in that frequency-agile modems for each circuit are required. In essence, the satellite/modem combination can be thought of as behaving as a distributed frequency-switched telephone exchange (see Figure 1).

In 1995 Telstra announced that they were introducing a digital DAMA service and that they would not be augmenting their analogue network. At the same time INTELSAT, the major world-wide satellite consortium, indicated that they would be introducing their digital DAMA service in the Pacific region in mid 1997. An implication of these moves is that Tokelau would be exposed to risk by adopting any given DAMA service if no other countries in the Pacific were to also move to this same service: calls to other Pacific Countries using the other DAMA service would automatically force double satellite hops. Double hops are undesirable due to the time delays they introduce into a call, being annoying to telephone users as well as slowing throughput for data circuits. In addition, the financial viability of two competing DAMA services in the Pacific is considered doubtful.

In the final analysis, it was determined that only Telstra's service would be ready in time to meet the Tokelau project's timetable and that no advantage could be ascertained in waiting for the INTELSAT DAMA service. Accordingly, it was decided to use the Telstra service, which uses a transponder on the INTELSAT 701 Pacific Ocean Region satellite at 174°E.

A network plan was accordingly prepared in October 1995 which set out the transmission and signalling requirements, numbering scheme and operational requirements. It became apparent that a fully featured PABX (Private Automatic Branch Exchange) would meet almost all switching and transmission requirements and would cost an order of magnitude less than even a basic Central Office exchange. In addition, standard PABX features could be easily adapted for the Tokelau network, including off-the-shelf call detail recorder billing systems. The trunking scheme is given in Figure 2.

Given the relatively tight budget the project had to work with, it was agreed that there was no need for redundancy in the satellite and exchange equipment. This significantly reduced the equipment cost without significantly compromising the standard of service. All the equipment is modular and so change-out of a faulty unit is rapid and straightforward.

In December 1995 tenders were called for the supply and installation of three 7.3 metre Standard F3 satellite earth stations, telephone exchanges, DC power plant and a billing system. Disappointingly, all the tender prices were high, mainly on account of the remoteness of the sites. Contract negotiations were concluded in March 1997, co-incidentally with Telstra, for supply of cheaper 4.5 metre Standard F1 Case antennas, Codan satellite equipment, 100-line Northern Telecom Option 11 PABX's, SwitchView billing system and Switchtec 48V rectifiers. Smith and Jones signalling converters were also to be supplied in order to carry out signalling functions not supported by the PABX, such as C-11 distant operator access signalling, and to provide a standardised interface.

Tokelau undertook to build the antenna foundations, and this was completed under the guidance of the Project Manager and after a geophysical survey had been first carried out by PLT Consultants of Western Samoa. Each foundation consists of a seven cubic metre reinforced concrete slab, which turns out to be at the limits of the construction expertise available in Tokelau.

Telstra provided three installation teams, who arrived in Tokelau in late October 1996 and, in spite of a number of difficulties, handed over the equipment for provisional acceptance in mid December 1996. Figure 3 shows the Fakaofo antenna being assembled.

3. Local access network

At an early stage it was decided to closely align the Tokelau local access network practices to those employed by Telecom New Zealand, principally for ease of supply and also because their practices are reasonably well proven. As most Tokelauans live in New Zealand it is expected that most non-rental customer premises equipment, such as facsimile machines and telephones, are likely to originate from New Zealand.

It was agreed to provide for individual service using underground reticulation. The marginal cost of providing individual service over community telephones or party lines is small and, by allowing for telephones in each house, incoming calls from more affluent relatives in New Zealand could be expected to be easily terminated. Narrow streets coupled with overhanging trees make overhead reticulation, which in any case would be unlikely to survive a cyclone, impractical.

In February 1996 a contract was awarded to MM Cables of Christchurch to supply some 16 km of 0.4 mm polyethylene insulated, grease filled (PEFUT) cable. Included in the contract were three km of 100-pair armoured cable which were laid across the lagoon to connect Fale to Fenuafala, the two inhabited islets of Fakaofo. Nearly all of

the remaining cable is laid in 50 mm PVC duct pipes to allow for flexibility in the future and to protect the predominantly 50-pair cable.

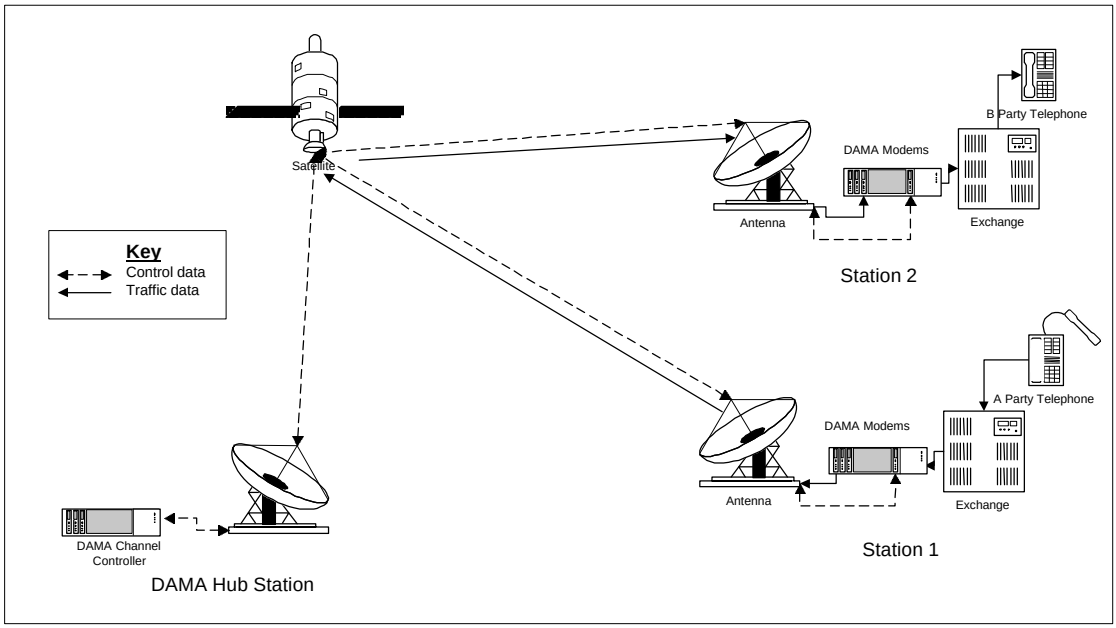

FIGURE 1. DAMA operation. The exchange at station 1 selects a free DAMA traffic modem, which in turn causes its control modem to signal the hub station via the fixed control channel. The hub directs the traffic modem at station 1 and a free traffic modem at station 2 to operate on a common traffic channel, thus connecting the two modems and allowing the call to be set up.

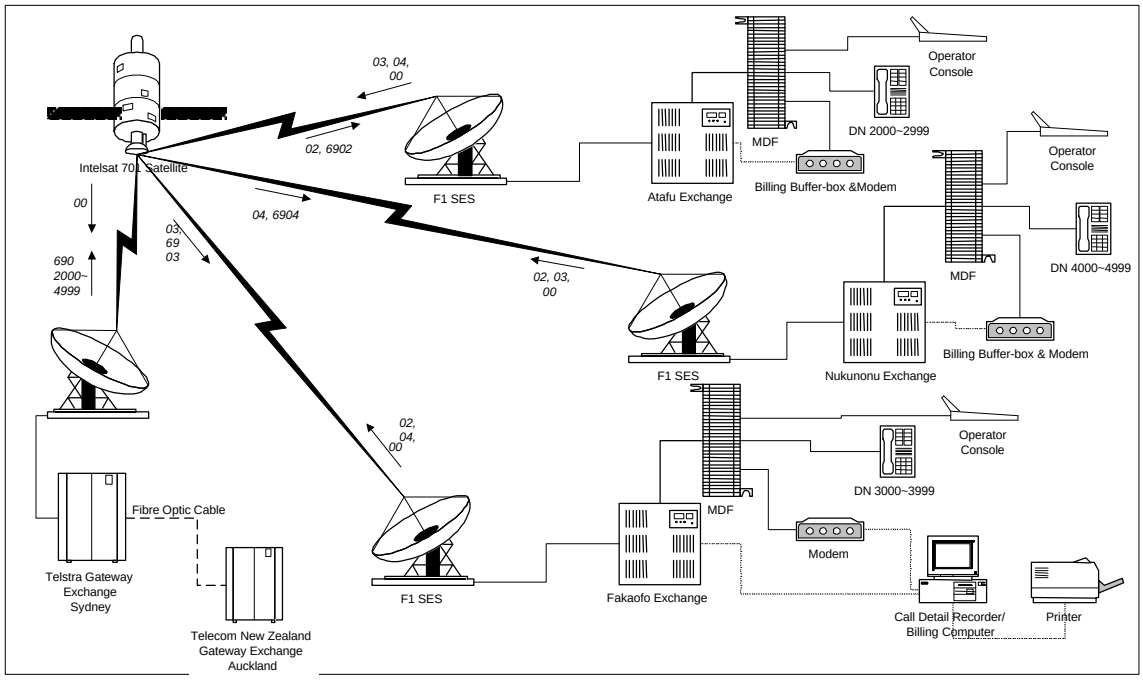

FIGURE 2. Simplified network plan.

FIGURE 3. Installing petals on the Fakaofo antenna.

The longest cable run is in Fakaofo, a distance of almost 3400 metres. This puts the furthermost subscriber just at the transmission limits for the PABX line cards. Most cable runs are less than 400 metres.

Telecom New Zealand plastic joint pits are located every 50 metres or so to provide access to subscribers. In the pits the distribution cable is looped into Raychem Radi 100 radial distribution closures where the underground subscriber leads are connected. Telecom New Zealand two-wire BT wall sockets are used to terminate the subscriber leads. The sockets have a tropicalised coating. Alcatel 500 telephones are the standard rental telephone, although subscribers may own their own telephones if they wish, provided that the instruments comply with New Zealand Telepermit requirements. The cabling was completed in April 1997 and connection of subscribers has been on-going.

Three Anritsu cardphones are provided for public use in each atoll. These were supplied and programmed by Telstra Cardphones. The cardphones adjacent to the exchanges are powered from the exchange mains-essential supply, while the remainder are only operational when the village power supply is operating.

4. Electrical services

The most enduring problem encountered throughout the project was the unreliability of the village mains power supplies. The diesel engine-alternators for the villages are scheduled to run from 9:00 am to 1:00 pm and again from 6:30 pm to 11:00 pm. However, the village power schemes are in advanced decline and outages from between five minutes and five days are common. At Nukunonu, the village power was out of commission for several months at one stage. By the time the telecommunications equipment was installed, all the village power supplies had already reached capacity and it turned out to be impossible to connect to them.

Initially it was hoped to install solar photovoltaic cells to power the telecommunication plant, and considerable work was spent in determining how best to do this. Wind power was also considered, but there is a shortage of suitable sites and so it was not further investigated. Unfortunately no budget provision had been allowed for installing solar panels and no source of funding was able to be procured. It was agreed that standby engine-alternators would have to be installed even if solar panels were used, as a severe cyclone would probably damage a solar array, and at a time when it would be most needed.

At the same time that this decision had to be made, the Tokelau Public Works Department embarked on a plan to upgrade all the village power schemes with the promise of 24 hour electricity. To date, the new scheme has not eventuated and the telecommunications standby engine-alternators have been operating as the prime power source for the telecommunications network. The standby engine-alternators are 5 kVA Lister TS2 sets supplied under a contract awarded in July 1996 to BTR Sales and Services. The sets are complete with an autostart panel which monitors the equipment battery for low voltage.

The 48 volt 2200 Ahr Absolyte IIp sealed equipment batteries are dimensioned to charge during the hours when the village power scheme is scheduled to be operating. They have sufficient capacity to carry the equipment for three to four days should both the village and telecommunications standby engine-alternator fail.

Critec sinusoidal inverters rated at 1 kVA provide a mains-essential supply for the test instruments, local cardphones and the billing equipment. The inverters and all other equipment are powered from the 48 V batteries.

5. Buildings and building services

In light of the intermittent nature of the mains power supply, it was clear that conventional environment control for the equipment would be both impracticable and expensive to operate. This conclusion was further reinforced by an obvious shortage of mechanical skills available to maintain air conditioning equipment. Thermocell Ltd of Christchurch developed and installed three sets of passive STAR (Store Transfer And Radiate) cooling systems which take advantage of the remarkably constant diurnal temperature variations experienced in the tropics.[2] The coolers have no moving parts and are maintenance-free. Figure 4 shows the internal arrangements of the coolers. The night-time air temperatures in Tokelau rarely drop below 26 °C, resulting in an equipment room temperature with the coolers installed of 32 °C ± 2 °C, as predicted. This temperature range is well within the equipment limits, but is a little high for optimum battery life. However, the reduced battery life is more than compensated for by the absence of maintenance and running costs and the inherent reliability of the cooling system.

James Hardie Bondor structural insulated panel kitset buildings were erected to accommodate the telecommunication equipment at Nukunonu and Atafu. The 4220 mm x 4820 mm enclosures are mounted on 1800 millimetre high concrete foundations to ensure that the buildings and equipment will survive cyclonic tidal surges, for under such circumstances most of the atolls become inundated with sea water. Indeed, as is true for most of Tokelau, all of the sites are less than 2.5 metres above mean sea level. The equipment buildings are designed to survive winds exceeding 200 kilometres per hour. The Nukunonu site is shown in Figure 5.

FIGURE 4. Fakaofo equipment room showing the STAR coolers on the right-hand wall.

FIGURE 5. Nukunonu site. From left to right: equipment building with STAR cooler fins on roof, INTELSAT antenna, and PEACESAT antenna.

At Fakaofo, the existing radio building was extended to accommodate the equipment, a centralised spares storage and technician work area, and the administrative headquarters. The extensions were constructed in poured concrete using local building techniques. Poured concrete is the favoured Tokelauan construction medium, proving to be fast and economical, especially as cement and reinforcing bars are straightforward to unload from the supply ships.

At each site a small poured concrete engine shed was constructed, also with 1800 millimetre high foundations.

Testing of the local coral sand and aggregate had shown that local materials would be unable to provide the necessary concrete strengths. Seventeen cubic metres of volcanic aggregate, packed into flour sacks to enable man-handling, were imported from Western Samoa to each site in order to construct the building and antenna foundations.

6. Logistics

The logistics of getting personnel and equipment to Tokelau are extraordinarily difficult. The supply ships from Apia visit once every four to six weeks, although delays between ships of up to two months are not uncommon. There are no wharf facilities and so all goods are off-loaded from the drifting supply ship into lighters, which then navigate the reef passage to unload on to the beach. The reef passages are difficult to negotiate if the sea is running more than a light swell and water damage is always a possibility from splashes, surprisingly frequent heavy rain, or very rarely, capsizes. From the beach, the plant and equipment are man-handled to the site. Fortunately most Tokelauan men are impressively strong, although handling the 2.6 tonne drum of armoured cable required the assistance of every able-bodied man in the village (Figure 6).

FIGURE 6. Unloading the 2.6 tonne armoured cable drum from a lighter, Fakaofo.

There is only a single, co-operative village store on each atoll which sells bare essentials - provided they have not run out, which is often the case. Thus, all equipment and plant must be specifically ordered, including all otherwise inconsequential consumables. Shortages of diesel and petrol impose their own difficulties. The petrol is used exclusively for running outboard motors - there are no cars - and when it runs out, workers cannot travel from one islet to the other and consequently cannot get to work.

The village elders control most aspects of life in Tokelau, and decide each week which projects in the village are to be progressed. While they did understand the importance of allocating labour for construction of the network, cultural and fishing requirements often took priority. Given the subsistence existence of most Tokelauans, fishing rightfully takes precedence over telecommunications network construction.

Ancient human remains were uncovered during trench excavations. They posed no problems and were reburied in the village cemetery as a matter of course.

7. Performance

Apart from some minor “teething” problems, the planned system is now performing to expectation, with all government departments and some 150 residential subscribers connected. The network is heavily used, and new subscribers are still being connected. The network was dimensioned for 60 subscribers at each atoll, with a long-term demand for 90 lines. Currently there are some 110 subscribers on Fakaofo alone. Toll traffic has also exceeded forecasts by almost a factor of two, although demand can be expected to drop as the novelty wears off. This has caused some quite considerable trunk congestion and it is likely that one to two additional DAMA circuits will have to be installed to meet demand.

Problems were initially encountered with the DAMA modems, which incorporate highly sophisticated speech compression algorithms. The modems are scheduled for upgrading to a later version software in July 1997 which will overcome circuit degradation currently experienced on some calls. A number of trivial failures in the earth station and engine-alternators caused some anxiety shortly after cutover as there were no ships available for six weeks to transfer spare parts.

Due to the unstable village power supplies, the telecommunications stand-by engine-alternators have been used as the prime mains power source for each of the stations. This has led to higher than anticipated use of consumables and accelerated maintenance requirements. Given the low expertise in diesel engine maintenance available in Tokelau and the difficulties of obtaining consumables, this situation is highly undesirable.

The PABX and DAMA modems operate under software control, and the man-machine interfaces to these are arcane. In spite of supplier training on the systems, they continue to be a source of consternation to the technicians. As they gain familiarity with the systems this becomes less of a problem.

When the network was being planned it was clear that a trade-off between ideal spares holdings and affordable stock levels would be necessary. This was also true for the specialised test equipment, especially considering that a single spectrum analyser, used for monitoring the satellite links, costs in excess of NZ$70,000. The inter-atoll catamaran, the *MV Tutolu*, is theoretically capable of travelling between any atoll in around five hours' sailing time, costing around NZ$1,000 for a round trip. Accordingly, a worst case three-day delay in procuring parts from a centralised spares holding was calculated. In practice, the *MV Tutolu* has been beset by mechanical and other problems, with the result that the calculated turn-around times for spares have not been met.

8. Infrastructure

The project included establishing a sustainable telecommunications business. The first task was to determine ownership of the network. After evaluating the alternative ownership options, which included government department, privately owned, co-operative and government-owned corporation, it was decided to take the innovative step of establishing Telecommunications Tokelau Corporation (Teletok) as a community-owned corporation which is to operate in a not-for-profit manner.[3] This recognised the unique communal culture of Tokelau.[4] All excess revenue, after depreciation and operating expenses that are not required to augment the network, are to be returned to users of the network in the subsequent financial year. Teletok also has monopoly rights to provide telecommunication in Tokelau. The *Tokelau Telecommunication Rules 1996*, which established Teletok, was the first legislation to be passed by the Tokelau General Fono under new powers given to it under the New Zealand *Tokelau Amendment Act 1996*.[5]

Subscriber credit control had been recognised as a potential problem from the outset. As there is virtually no cash economy operating in the conventional sense in Tokelau, local feeling was that subscribers would be at extreme risk of incurring debts which neither they, nor Teletok, could afford. The solution to counter this was to adopt the stratagem of toll-barring all telephones. To make toll calls, most subscribers must use a debit phonecard with the cardphones, or place calls through an operator. Government departments and subscribers with an adequate credit rating are offered PIN numbers which allow them to place toll calls from any telephone with charges being debited to their account.

Attractive sources of additional income to Teletok have been identified, including philatelic phonecard sales and international premium rate services. The latter takes advantage of arbitrage pricing of certain international toll routes, and is popular for audiotext service providers. These avenues are currently being explored.

A number of international ITU staff and consultants, including some from New Zealand, were recruited during the project for short-term missions. They have provided invaluable training and learning opportunities for the Tokelauan business and technical staff. In addition, three of the Tokelauan technicians were attached to Telecom Cook Islands for three months' work experience while two other staff have undertaken study tours to telecommunication organisations in New Zealand, Australia, and Fiji.

9. Future developments

The outcome of the competing DAMA networks in the Pacific remains uncertain. Since Tokelau cut-over, Tonga has begun construction of a Telstra DAMA network, while Telecom Cook Islands, with Telecom New Zealand prompting, has begun evaluating INTELSAT DAMA. As both systems operate with a standard 70 MHz intermediate frequency and have identical satellite link parameters it is technically possible to swap out the satellite modems from one system to the other.

Internet e-mail and file transfers are likely to be of immense utility considering Tokelau's physical isolation. Currently there are some e-mail users, but the potential has yet to be fully developed. It is intended that Teletok will set up and operate a full data network in Tokelau, using LANs (local area networks) and dial-up modems for use by all government departments. It is not clear if the world wide web will be a viable option as data links through DAMA are

currently limited to 9.6 kbps. Telstra is investigating a bandwidth-on-demand service for DAMA which would be useful in this respect if tariffed appropriately.

In June 1997 the New Zealand Official Development Agency granted NZ$160,000 for the conversion of the network to solar power. A hybrid diesel-photovoltaic system is the most likely outcome and could be operational in late 1997.

10. Conclusion

A telephone network was designed for and built in Tokelau. It cut-over for full international traffic in April 1997, marking Tokelau as the last country in the world to receive telephone service. The network consists of three 4.5 m Standard F1 satellite earth stations using the Telstra digital DAMA service. Local calls are switched by PABX's. Individual service is offered to subscribers using underground PEFUT cable based on Telecom New Zealand outside plant practices and standards.

A community owned corporation, Teletok, was established to own and operate the service.

The logistics involved in establishing the network had to take into account poor communications and difficult transportation. The intermittent local power supply has led to the use of STAR passive cooling for equipment room environment control and has forced the stand-by engine-alternators to become the prime source of ac power.

The network is operating satisfactorily.

11. Acknowledgements

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