Wireless Local Loop and Packet Radio Technology for Developing Communities

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Abstract— **In developing countries there is an increasing demand for telecommunications and Internet access. The current problem, especially in Africa, is to find solutions which can provide underdeveloped countries with a satisfactory network. This requires a relatively fast roll-out at low-cost. Modern wireless system claim to offer quick and easy deployment. However, in many cases the wireless system deployment is delayed because adequate radio plans have to be designed, and they are not optimized for Internet and computer communications. Multihop packet radio can offer computer communication in an easily deployable ad-hoc wireless network which does not require frequency planning. However, voice traffic is not easily implemented on packet radio networks due to the bursty and delayed traffic characteristcs. A multihop packer radio network is proposed which offers voice and Internet communications.**

I. Introduction

In developing countries there is an increasing demand for telecommunications and Internet access. The major hurdle for most of these countries is the lack of adequate telephone network infrastructure. The current problem, especially in Africa, is to find solutions which can provide underdeveloped countries with a satisfactory network.

Wireline telephone networks (or Plain Old Telephone System - POTS) are not suitable for deployment in urban township or rural communities because of the expense of the wire and the work required to lay wire underground or on support structures overhead. As a result, rollout of wireline systems takes considerably more time than wireless systems. Network planning in urban townships is difficult because of the network complexity that results from the close proximity of houses due to the high density population in these areas. Furthermore, deploying the network is difficult logistically because there is little space for equipment in the spacing between houses.

Township domains tend to be large high density domains containing hundreds of thousands of people in a few square kilometers. Therefore it is difficult to achieve a good radio plan in these areas, especially if more than one provider intends to compete in the same domain. If very small cells could be used and two or three cellular providers could compete in the same domain, the cost of the equipment and installation would be expensive because of the large number of base stations that would be required.

Recently many new systems, such as DECT and PCS, have been introduced into the market place to provide solutions to some of the above problems. Most of these systems require line-of-site (LOS) between the base station and the user terminal within the township area. This requires the use of tall base station antenna structures.

As a different approach to providing a similar service like the new wireless systems, packet radio used in a multihop network is proposed for use in a wireless local loop system. Packet radio offers some advantages over the current systems, such as: reduced power requirements for user equipment, smaller antennae, removes the need for direct line-of-site of a base station, almost completely removes the need for radio planning, and enables quick deployment. A multihop network, however, has inherent traffic delays and does not guarantee a high grade of service (GOS).

The network proposed here is to be used as a local network only serving 'last mile' connections within the community. The reason that self-organising networks are of interest is that they are quick to deploy, requiring little management due to their self-organising ability. A multihop packet radio network is suitable for providing Internet connectivity and capability because packet radio information transport is based on digital packet switching, routing and transmission.

Multihop packet radio networks are subject to delay, throughput, and routing constraints. These characteristics have been researched for the past decade, and are now better understood. The multiple access protocols of multihop networks have also matured, and have been applied to wireless Internet gateways[1], and community computer networks such as the Rooftop Community Network [7].

The nature of this paper is concerned with organising existing techniques to solve the problem of providing Internet and voice communications to underdeveloped communities, rather than developing new techniques. Section II explains the fundamental concept of a multihop packet radio network. Section III describes the fundamental channel access techniques used in packet radio networks. Results are also presented for a relatively new channel access protocol called FAMA-NCS used in the conceptual design of the proposed network. Section IV explains the use of spread spectrum CDMA for easing network deployment and improving signal reliability. Section V deals with link reliability and acknowledgements schemes. Section VI describes a hybrid routing strategy for routing data and voice. Section VII explains the constraint imposed on packet delay due to voice quality requirements. The purpose and choice of a vocoder for voice compression is described in section VIII. Section IX explains how malfunctioning nodes are handled. Section X deals with the application of the proposed network to developing rural and urban township communities. The conclusions and some recommendations for further research are presented in section XI.

The objective of this paper is to show that various communication techniques and technologies exist which can be combined in innovative and novel ways to solve existing communications problems.

II. Multihop Packet Radio Network

Packet radio networks extend packet switching technology into the environment of broadcast radio. They provide data communications to users over a broad geographic region. They are based on the notion of packet switching applied to radios sharing a single wideband channel. In general, data in binary form (digital information) is transferred. This allows for the transmission of computer data or digitized voice. The network proposed is a fixed topology multihop packet radio network.

A. Store-and-Forward Operation

In general packet radio usually operates in a store-and-forward mode. This is explained with the aid of figure 2.

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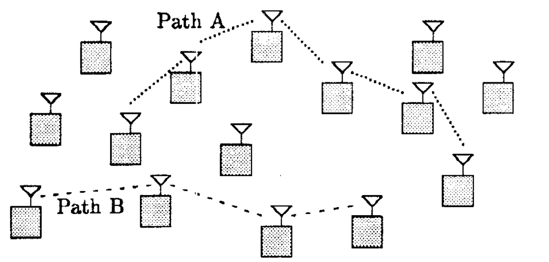

Fig. 1. Multihop PR network data routing and delivery: path A and path B deliver packets to different nodes

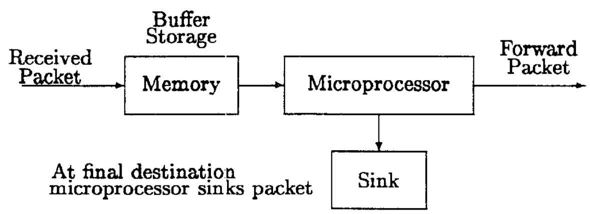

Fig. 2. Store-and-forward operation

A typical packet radio unit (PRU) consists of a radio, antenna, and digital controller. Packet radio units will also be referred to as network nodes. In multihop networks the radio provides connectivity to neighbouring nodes, and usually cannot establish a direct radio link with all the nodes in the network. Nodes which are not directly detectable by a node are called *hidden* nodes.

The store-and-forward operation is provided by the controller to enable the relaying of packets to accomplish connectivity between source and destination nodes. The digital controller receives the packet from a neighbouring node, *stores* the packet in memory, analyses the packet for control and routing information, and then (if neccessary) *forwards* the packet by sending it to the transmitter for retransmission. The signal should then be received by a neighbouring node on the route to the end destination node. Figure 1 shows typical delivery paths as packets are forwarded through a multihop ad-hoc packet radio network. A packet may travel via many nodes before it arrives at the end destination node, hence the name *multihop packet radio network*.

III. Channel Access

A packet radio network requires a set of protocols to operate at various network levels: from the lowest level where a packet makes a hop, to higher levels that ensure reliable data transfer and routing, as in any packet communication networks. In this section we briefly look at *channel access protocols*, namely: ALOHA, CSMA, BTMA, FAMA-NCS, and the application of spread spectrum to packet radio.

A channel access protocol defines the conditions under which a node may access a channel. For many protocols, these conditions are expressed in terms of the state of the node in question, and the state of neighbouring nodes in the network. The effectiveness of the rules embodied in the access protocol are constrained by the information that can be acquired locally at the node, such as the state of the receiver at the node, and the state of the transmitters in the radio locality. The success of a protocol depends on the ability of a node to dynamically acquire knowledge about the state of the other nodes, which depends on the particular channel signaling scheme and code-assignment scheme used. Capture properties also affect the choice of access protocols.

A. ALOHA, CSMA and BTMA

ALOHA (also referred to as *pure* ALOHA) permits a node to transmit packets any time it desires. All network nodes use the same broadcast channel, and we assume for purposes of this paper that all antennae are omni-directional. If part of a user's transmission overlaps with another user's transmission in time then the two transmissions are considered to have collided, and have corrupted (sometimes completely destroyed beyond correction) each others transmissions. If one of the transmissions have a significantly larger power level than the other signal then, in general, the stronger signal will be correctly received. This effect is called *power capture*.

If all the signal power levels of transmissions at all the receivers in a network are equal then we say that we have a zero capture network because there is no power capture effect. In the case of a zero power capture network a collision will always occur in the three situations described by Figure 3.

An acknowledgement signal from the receiving node is used to indicate to the transmitting node if the transmission has been received successfully. A negative acknowledgement signal (NACK) is transmitted to indicate a corrupt reception. If a NACK is received then the node will retransmit the packet after a random period of time (*backoff interval*) to avoid continuously conflicting with transmissions. By using ACK and NACK, a packet radio system employs perfect feedback, even though traffic delays due to collisions may be high.

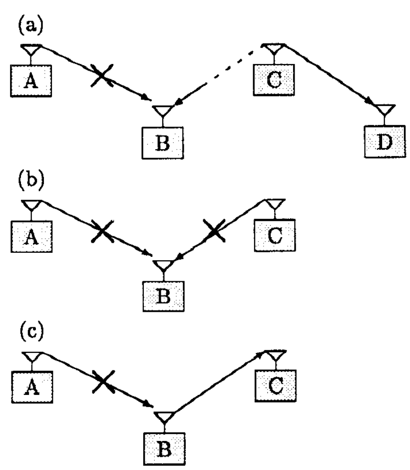

Fig. 3. (a) Transmission C to D collides with transmission A to B: transmission C to D succeeds, transmission A to B fails. (b) Transmission A to B collides with transmission C to B: both transmissions fail. (c) Transmission A to B collides with transmission B to C: transmission B to C succeeds, transmission A to B fails

The usual maximum theoretical value reported for channel utilisation using ALOHA is about 18% [5]. ALOHA exhibits low channel utilization, but it has been shown to be superior to fixed assignment schemes such as FDMA and TDMA when user traffic is bursty and low packet delay is essential, [5] [18]. A modification to ALOHA called slotted ALOHA improves the channel efficiency to a maximum theoretical value of 37% [4].

An improvement to the ALOHA and slotted ALOHA protocols can be achieved. It is possible to reduce the number of possible collisions in the random access channel by requiring the radio units to sense ('listen to') the channel prior to transmission, and to inhibit transmission if a carrier is present. This technique is known as Carrier Sense Multiple Access (CSMA) and can take different forms such as [17]: non-persistent CSMA, 1-persistent CSMA, p-persistent CSMA, and CSMA with carrier detect (CSMA/CD).

The simple non-persistent CSMA acts as if a collision occured when it detects a carrier, and reschedules the packet for retransmission at a later time.

When two nodes hidden from each other simultaneoulsy transmit to another node not hidden to either transmitting node then a collision occurs. This known as the hidden known problem (Figure 3(a) and Figure 3(b)). The *hidden node* problem can be alleviated by the use of a *busy tone* signal which is transmitted on a separate channel, say a *busy tone channel*, by a receiving node to indicate that the node is receiving a packet and that the multiaccess channel is in use. This technique is known as Busy Tone Multiple Access (BTMA). The busy tone is used to inhibit the receiving nodes' neighbours from transmitting on the channel. This will prevent collisions from neighbouring node transmissions. Any node within range of the receiving node with a packet ready for transmission, sensing the busy tone, will reschedule the transmission. BTMA outperforms both ALOHA and CSMA [5], however it does not perform as well as FAMA-NCS described in subsection III-B.

B. Floor Acquisition Multiple Access with No Carrier Sensing - FAMA-NCS

The term *floor* is used to describe the channel in the vicinity of a receiving node. FAMA-NCS guarantees that a single transmitting node (or sender) is able to send data packets free of collisions to a given receiving node (or receiver) at any given time. FAMA-NCS is based on a three-way handshake between the transmitting and receiving nodes, in which the sender uses nonpersistent carrier sensing to transmit a request-to-send (RTS) signal and the receiver sends a clear-to-send (CTS) signal that lasts much longer than the RTS and serves as a *busy tone* that forces all hidden nodes to *back-off* long enough to allow a collision free data packet to arrive at the receiver from the sender.

FAMA-NCS requires a node who wants to transmit one or more packets to acquire the floor before transmitting the packet train. The floor is acquired using an RTS-CTS exchange. To acquire the floor a node transmits an RTS using *carrier sensing* or *packet sensing*. Packet sensing corresponds to using the ALOHA protocol for transmitting the RTS as a packet containing control information requesting the floor. CSMA is employed for sending the RTS using carrier sensing. A CTS is only returned once the requested node has received an error free RTS that is addressed to itself. The requesting node (sender) knows it has acquired the floor when it receives an error free CTS addressed to itself.

After acquisition the floor holder (sender) is able to transmit packets without collisions occuring on the channel. Any reliable link mechanism can be implemented on top of FAMA-NCS between the floor holder and the nodes with whom it wants to communicate. Nodes that do not have the floor are forced to wait a minimum predefined period of time (a minimum of twice the maximum propagation delay) before being able to contend for the floor. When a node, ready to transmit data, detects that the floor has already been acquired then it reschedules its bid for the floor.

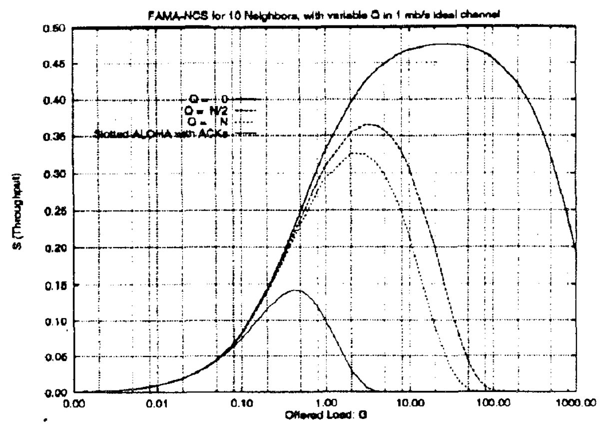

Fig. 4. Comparison of results for slotted ALOHA and FAMA-NCS with various Q values

Figure 4 (from [12]) shows the comparison of results for slotted ALOHA and FAMA-NCS with various Q values (explained below).

[12] assumed a network where each node had 10 neighbours for varying Q values. $Q = 0$ means the network is fully connected, $Q = N/2$ means that half the neighbours of any node are hidden from a neighbours' neighbour. $Q = N-1$ means that all the nodes are hidden from their neighbours' neighbourhoods. [12] assumed network parameters with a propagation delay of $6\mu s$ (one mile), 500-byte data packets, 25-byte RTS, and a 50-byte CTS, and presented results for a 1-Mb/s channel with zero preamble and processing overhead based on the Utilicom 2020 radio transceiver. Using the Utilicom model 2020 transceiver, results in the transmitter using $11ms$ to send an RTS and be ready to receive a CTS. If transmission overhead is included, then a 500-byte data packet becomes $25ms$ long.

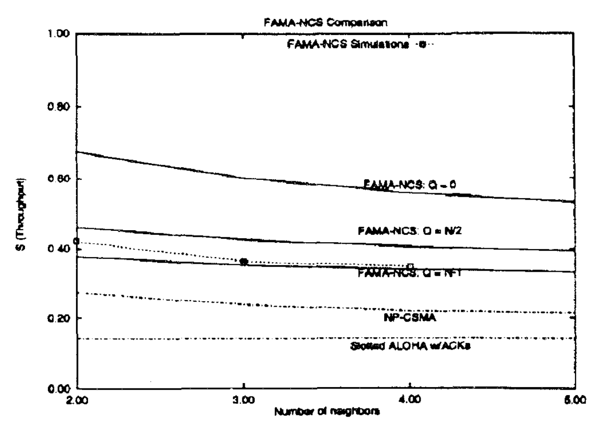

Fig. 5. Throughput versus degree of nodes in an ad-hoc multihop network using FAMA-NCS or CSMA

Figure 5 (from [12]) shows a plot of the maximum throughput for FAMA-NCS in multihop networks versus the degree of nodes for various values of Q. The degree of nodes means the number of nodes in the vicinity of another node, or the number of neighbours per node.

The results presented by [12] show that FAMA-NCS is a better choice than CSMA for an ad-hoc multihop packet radio network. The results obtained from the use of the Utilicom model 2020 transceiver indicate that radio parameters significantly affect the performance of FAMA-NCS in ad-hoc multihop packet radio networks. With good carrier sensing and short turn-around times (time to ramp up the transmitter or the time to ramp down the receiver), throughput can be substantially increased. [12] also claims that FAMA-NCS performs better than all prior proposals based on collision avoidance protocols, such as MACA [14], MACAW [19], and IEEE 802.11 DFWMAC [8] [2], in the presence of hidden terminals.

BTMA and FAMA-NCS are collision avoidance channel access techniques. The conceptual design of the proposed multihop packet radio network would use FAMA-NCS because FAMA-NCS clearly shows better performance than other existing multihop packet radio network channel access techniques. FAMA-NCS has also been used in the WINGs wireless internet gateways with success [1]. It has proven itself in practical applications, and is therefore chosen as the channel access technique for the proposed network.

IV. Spread Spectrum CDMA

Spread Spectrum CDMA uses psuedo-random number (PN) codes to modulate a signal on to a wide frequency band. If the codes are chosen to be orthogonal, as is the case in CDMA, then bandwidth efficiency is improved in a multi-user environment [17]. Codes can be automatically assigned to nodes in the multihop packet radio network during network/node initialization; they may also be reused in large networks. This practically removes the need for radio planning; which usually takes a relatively long time for narrowband systems unless dynamic frequency allocation is implemented, such as in DECT systems [9].

The other benefit of using CDMA is that it has inherent coding gain [17] which results in CDMA systems having excellent robustness in the presence of multipath and Rician channel fading effects. The code aspect also allows increased network capacity [17] because adjacent nodes will not cause a collision if they transmit using different codes [16]. In other words, a collision of type (a) described in figure 3 will not occur.

In the proposed network, a receiver-directed bit-homogeneous code assignment scheme [16] [6] is used for the preamble of the data packet. The data following the preamble is coded with a transmitter-directed bit homogeneous code [16]. The preamble contains a code identifier that instructs the receiver which code to use to despread the received packet transmission. In this scheme the preamble is more prone to collision than the packet. Once the error free preamble has been received then the probability of the packet collision is negligible because no other transmitter will be assigned the same code in the two hop radius surrounding the transmitting node.

V. Link Reliability and Acknowledgement Scheme

The data link layer of a network performs the functions that enable a reliable link between adjacent nodes. Usually an acknowledgement mechanism is used to support such a link, for example automatic request queing (ARQ). ARQ uses redundancy for the purpose of error detection, and is generally used with channels which are commonly called *compound-error channels* [11]. If data received by a node is corrupt and an error is detected then a negative acknowledge (NACK) is sent in reply (feedback) and acts as a request for the data to be retransmitted. If the data is error free then a positive acknowledge (ACK) is usually sent informing the transmitting node that data was received correctly.

End-to-end (ETE) acknowledgement, which requires the final node in the route to acknowledge the source, and hop-by-hop (HBH) acknowledgements, which involves per hop acknowledgements, are two possible acknowledgement schemes that can be used to ensure link reliability between the source and final destination node. The disadvantage with ETE acknowledgements is that the total average delay is increased, relative to HBH acknowledgements, between source and destination node pairs [5] [10]. An automatic request for transmission (ARQ) type HBH acknowledgement is preferred. Any corrupted packets cause the receiving node to transmit a negative acknowledgement (NACK) to the transmitting node as each hop is traversed. In this way link reliability is ensured.

Forward error correction is also necessary in wireless links [17]. The use of FEC will reduce the number of ARQ retransmission requests, thereby increasing link utilisation and improving packet transport speeds. A careful balance between FEC and ARQ must be reached so that link data rate and reliability are optimised.

VI. Routing

Two general classes of routing algorithms exist: incremental routing and source routing algorithms. In general, incremental routing requires less control overhead in packets thereby providing better network utilisation than source routing. However, it is possible to use a source routing strategy to reserve a path, and thereby reduce overall packet overhead.

We propose a hybrid routing strategy. Voice traffic is given priority over computer data and Internet traffic. Voice traffic is routed using source routing and each voice packet is given a priority flag that indicates that it should be processed before data packets waiting in the nodes transmit buffer. Data packets are routed using the incremental ALVA algorithm [13]. Simulations by Behrens and Garcia-Luna-Aceves [13] show that even with a one level hierarchy ALVA outperforms OSPF [15] in terms of storage and communication requirements. Furthermore, with the use of hierachical addressing ALVA is more scalable than OSPF, and therefore constitutes the basis for a more efficient internetwork routing protocol based on link-state information. Data packets and voice packets are indentified by an indication bit in the packet header.

The disadvantage with this proposed scheme is that it requires two separate memory stores: one for the partial routing topology information required by ALVA, and the complete routing topology information required for source routing. One way to avoid this is to write software which allows both routing strategies to access the same information, but in the case of the incremental strategy only a subset of the information is accessable.

In the proposed voice packet source routing strategy an initial route is setup by a specialised packet sent from the source node to the final destination node at the end of the route. The route is calculated from the complete network topology information database that is stored in the source node. All other packets from the source node following this packet use an identifier which indicates to intermediate nodes that it is using the predefine reserved path specified in the first packet. The intermediate nodes will recognise the packet identifier and forward the packet to the next node along the reserved route.

This identifier requires minimal information and therefore reduces network overhead contained in the packet header of voice packets. The source routing strategy is useful for voice because it guarantees a route to the destination and minimises the voice packet header size, which reduces the packet length. Smaller packets have a reduced probability of collision during link transmissions because they require less transmission time than longer packets.

If a node forms part of a reserved route using the above mentioned source routing strategy, it is still able to be accessed by other data packets while it is not processing voice packets. The node can be used for routing other data and voice packets.

Various recovery methods can be applied in the event that a link along a source routed path (reserved route) fails. If a node fails then the source router will redirect the voice packets along an alternate path. The proposed network is for fixed telephones (i.e. nodes with voice facilities), not mobile application, therefore the event of a node or link failing is reduced, compared to mobile network nodes. Therefore only HBH acknowledgements are used.

In order to have a voice conversation via telephone, the users involved must be able to hear each other and talk to each other at the same time. They require full-duplex handsets. This can be achieved by having two voice packet routes between the users. For example, packets travelling across route 1 proceed from user A to user B, and packets travelling via route 2 travel from user B to user A.

The approach here is to use a FDMA technique at the node. The easiest way to achieve this is to have the transmit frequency different to the receive frequency. Such a node allows route 1 and route 2 to be assigned to the same nodes between users A and B. Thus the routes are the same but there packet transport direction is opposite. We call this combination of route 1 and route 2 a multihop packet radio voice channel.

VII. Packet Delay

Voice traffic is sensitive to delay. Voice packets are dropped if they arrive late at the final destination node. Each node has an associated processing time due to store-and-forward operation. A maximum delay of between 0.01 and 0.1 seconds is reported [17] as acceptable to deliver recognisable speech, and a maximum delay of 0.001 and 0.01 is acceptable for video and therefore multimedia applications in personal communications networks.

The propagation delay between nodes is determined by the distance a signal travels between the nodes. We have a cumulative delay when a packet travels multiple hops due to the cumulative propagation and processing delays. We see that the cumulative delay will also determine the maximum number of allowable nodes in a source-destination route. In the Rooftops Community Network the maximum number of allowable hops is six.

VIII. Vocoder

A vocoder is a speech coding device. Its purpose is to reduce the amount of information required by the receiver to allow for recognizable voice reproduction. In general, vocoders are complex devices and achieve very high economy of the transmission bit rate [17]. The IS-95 CDMA standard [17] specifies the QCELP13 vocoder from Qualcomm [3]. The QCELP13 has a maximum output data rate of 14400 bits per secong and thus reduces the traffic burden that voice would normally place on a data network. A QCELP13 vocoder is used to minimise voice data from any telephone signal, and because of it provides good voice reproduction quality.

IX. Handling Malfunctioning Nodes

If a node forwards information to another node and does not receive an ACK or NACK after a certain time-out period, then it will retry to access the node once more. If no response is received after a time out period then it assumes the node is malfunctioning. The transmiting node forwarding the information will then broadcast a special packet indicating which node is not operational. This will effectively erase the malfunctioning nodes' entry from all routing tables. This packet will also be forwarded to the network administration center informing them about the malfunctioning node. The node can then be investigated. In many cases the user of the phone will realise the malfunctioning node and try inform the network administrator.

The thransmitting node which determined the malfunctioning node will then redirect its packet to another neighbouring node to allow the packet to continue to its final destination.

X. Urban Township and Rural Application

A. Rural Application

The packet radio network can be applied to small rural communities that are very distant from major telephone or Internet switching centers. In this scenario the multihop network can be used as a local internet and supply an internet quality telephone service. It is expected that data traffic in these communities will be small until the community develops into a large community at which time they can upgrade the network to different technologies if possible and/or required.

The fact that the community is not near a major switching center means that a link must be made between the local multihop network and a switching center. The quickest way of doing this would be to use LEO or MEO satellites which will become available to South Africa and most other countries in 1998. The other option would be to install a microwave link. However, this may be more expensive than the satellite solution. This can only be determined when satellite service costs are known.

When the network is deployed, each user is provided with a node. In order to provide connection to existing network infrastructure, such as a public switch telephone network (PSTN), a network interface must be provided, an *interface node* (IN). The IN acts as a gateway to the packet radio network. Communication among other *local* network nodes continues without the use of the external network interface node. If a user wants to call someone outside of the network (e.g. in another city or country) then the call is routed through the interface node. The IN is therefore also used to connect the nodes to the global Internet.

B. Urban Township Application

In urban township communities like Khayelitsha, the high population density will create high demand for services. Effective voice communication may not be possible, however this will have to be determined through further investigation and research. The multihop network will still be able to provide Internet access. This is important especially in high density areas where networks are not easy to deploy. A self-organising packet radio network can be easily and quickly deployed.

An urban community is usually situated near a switching center and can be easily connected with a short distance microwave link or via a short underground G.703 trunking cable connection such as the one used by Telkom for their DECT system in Khayelitsha.

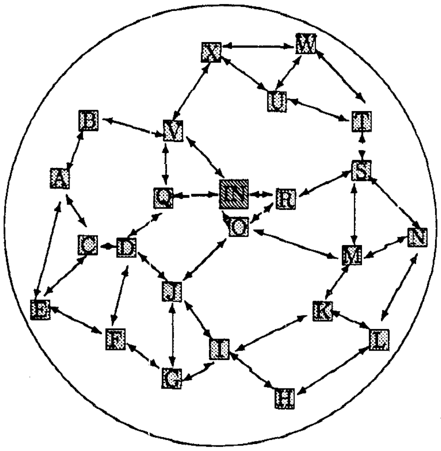

Fig. 6. A Typical Local Network

XI. Conclusion

We have shown that existing technology and communication techniques can be conceptually arranged into a feasible multihop packet radio network, which may provide wireless local loop (WLL) for both Internet and voice services.

Packet Radio has been suggested to overcome some of the problems associated with the terrestrial networks. The network proposed is a self-organizing multihop packet radio network. We have introduced the fundamental packet radio multiple access schemes: ALOHA, CSMA, and BTMA. FAMA-NCS. A multihop packet radio collision avoidance multiple access technique, was shown to outperform these multiple access techniques, and was thus chosen for the proposed network.

Spread spectrum was shown to be useful for allowing the network to be easily deployable. Once a network is installed it is activated and the nodes begin to acquire information about there neighbours. The nodes use this infromation to determine routing paths, and the signal spreading codes of there neighbours. The codes can be assigned to nodes in such a way that packet collision can be minimised and thus network throughput is increased.

Issues relating to link reliability have been discussed. Hop-by-hop acknowedgements are used in conjunction with a forward error correcting code to provide reliable link connectivity.

Incremental and source routing have been discussed. It was decided to opt for a hybrid routing approach where voice packets are routed using source routing and data packets are routed using the ALVA incremental routing algorithm.

The primary limitation on voice is the processing delay at the node (per-hop delay). In [17] a delay of more between 0.01 and 0.1 seconds is suggested to result in low voice quality. This means that if a 20 ms delay exists per-hop, then no more than five hops (0.1 seconds) can be made before voice quality is unrecognisable.

Frequency spectrum allocation of this network should be determined by the user data rate requirement and governmental regulations.

The Rooftops Community Network [7] is a multihop packet radio network that operates using Internet protocols, not the usual X.25 packet radio protocols, and has been shown to be successful with data rates as high as 1 Mbps. The Rooftops Company claim it can deliver Internet quality voice. This suggests that similar networks, such as the network proposed in this paper may do the same.

With improving radio and microprocessor technologies distributed computing networks such as the one proposed may be able to deliver acceptable voice quality and Internet services to small rural communities, and deliver acceptable Internet services to larger township type communities.

A possible area of interest that may be beneficial to study is the proposed hybrid routing scheme where voice is routed using source routing and data is routed using incremental routing. The software required to distribute spreading codes also needs to be developed to determine if codes can be assigned to nodes in a way that minimises collisions. The most important software that needs to be developed is an easy to use package that can simulate multihop packet radio network traffic.

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