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REDUCED COST ALTERNATIVES TO PREMISE WIRING USING ATM & MICROCELLULAR TECHNOLOGIES

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ABSTRACT

The cost of premises wiring keeps increasing due to personnel moves, new equipment, capacity upgrades etc. It would be desirable to have a wireless interface from the workstations to the fixed network, so as to minimize the wiring changes needed. New technologies such as microcellular personal communication systems are promising to bring down the cost of wireless communication. Another promising technology is Code Division Multiple Access (CDMA), which could dramatically increase the bandwidth available for wireless connections. In addition, Asynchronous Transfer Mode (ATM) technology is emerging as a technique for integrated management of voice, data and video traffic on a single network. The focus of this investigation will be to assess the future utility of these new technologies for reducing the premise wiring cost at KSC. One of the issues to be studied is the cost comparison of "old" versus "new", especially as time and technology progress. An additional issue for closer study is a feasible time-line for progress in technological capability.

SUMMARY

New technologies such as personal communication systems (PCS) and asynchronous transfer mode (ATM) hold the promise to usher in a new era of mobile multimedia communication. This could have significant impact at KSC in operations and in premise wiring cost. Switching networks have evolved from circuit switching to TDMA to packet switching. ATM is the next step in the evolution of switching systems, with the promise of carrying multimedia service on a single network. Cellular communication service is evolving from an analog FM system to a digital system based on TDMA. CDMA technology has also been proposed as an alternative for digital cellular. At present, the cellular business is driven by the voice market. But the lessons learned from the switching business indicate that cellular networks will evolve toward packet based technology e.g. ALOHA, for adapting to multimedia service based on ATM backbone network. The technology for building a multimedia terminal is already here. The challenge for industry is to design and standardize a packet based cellular network that can act as a wireless front end to the backbone ATM network. This may take about 8 years yet.

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LIST OF ABBREVIATIONS

ADPCM	--	Adaptive differential pulse code modulation
AMPS	--	Advanced mobile phone system
ATM	--	Asynchronous transfer mode
CDMA	--	Code division multiple access
CIR	--	Carrier to interference ratio
CRC	--	Cyclic redundancy check
CSMA	--	Carrier sense multiple access
DCT	--	Discrete cosine transform
DS	--	Direct Sequence
FDDI	--	Fiber distributed data interface
FDMA	--	Frequency division multiple access
FEC	--	Forward error correction
FH	--	Frequency hopping
FM	--	Frequency modulation
GMSK	--	Gaussian minimum shift keying
GSM	--	Groupe spatiale mobile
KSC	--	Kennedy space center
LAN	--	Local area network
MTSO	--	Mobile telephone switching office
NTSC	--	National telecommunication standards committee
OISD	--	Operational intercom system digital
OMI	--	Operation and maintenance instruction
OTV	--	Operational television
PCS	--	Personal communication system
PN	--	Pseudo noise
PRMA	--	Packet reservation multiple access
PRN	--	Packet radio network
QPSK	--	Quaternary phase shift keying
RF	--	Radio frequency
SPDMS	--	Shuttle processing data management system
SSMA	--	Spread spectrum multiple access
TDMA	--	Time division multiple access

I. INTRODUCTION

The cost of premises wiring keeps increasing due to personnel moves, new equipment, capacity upgrades etc. It would be desirable to have a wireless interface from the workstations to the fixed network, so as to minimize the wiring changes needed. New technologies such as microcellular personal communication systems are promising to bring down the cost of wireless communication. Another promising technology is Code Division Multiple Access (CDMA), which could dramatically increase the bandwidth available for wireless connections. In addition, Asynchronous Transfer Mode (ATM) technology is emerging as a technique for integrated management of voice, data and video traffic on a single network. The focus of this investigation will be to assess the future utility of these new technologies for reducing the premise wiring cost at KSC. One of the issues to be studied is the cost comparison of "old" versus "new", especially as time and technology progress. An additional issue for closer study is a feasible time-line for progress in technological capability.

In Section 1 we will outline the motivation for study of mobile multimedia technology at KSC. In Section 2 we will outline the current status, issues and trends in PCS and ATM technologies, especially as they relate to scenarios for development of mobile multimedia technology. Section 3 will assess the technological options of Sec. 2 against the requirements posed by the applications in Sec. 1. A reader wishing to get an overview without too much detail may wish to skip Sec. 2 and proceed directly to Sec. 3. Final conclusions are presented in Sec. 4.

1.1 THE PROMISE OF PCS TECHNOLOGY

Personal communication system (PCS) technology is a predicted outgrowth of current generation cellular communication systems. In the 1970s, mobile telephone service was expensive and available to the rare few. By the mid 80s, cellular technology made it possible to expand service to a large number of users in automobiles. By 1990, personal communications were emerging in the form of lightweight mobile telephones that could be used by automobile passengers as well as pedestrians. Yet, further improvements in mobile communications are needed. Present technology is mainly geared for voice communications. There is a need to develop data and fax services in the near future, and video services further down the road. Another critical issue is improving the management of bandwidth in order to allow closer to a universal service penetration. These issues are under active investigation [1]. Indoor mobile communication needs further development, in order to allow tether-less access in the home and office environments.

When fully developed, PCS technology promises to deliver an array of communication services to a portable hand-held unit at any desired location. Fig. 1 summarizes some of the features of future PCS technology. Visions of Dick Tracy and Star Trek will be fully realized. The PCS terminal will be lightweight, operable indoors and outdoors, so the same terminal will allow completely tetherless and mobile access to the network from home, office, automobile, or even out of town. Global roaming will allow the same terminal to be usable anywhere. Just imagine, your teenage daughter can start talking with her friend as soon as she wakes up, and need not hang up until she is ready to go to bed at night. Custom network services will be delivered on the basis of user identity, not terminal identity or location. This means custom services such as speed dialing, custom directory, call screening, billing authorizations, etc., will travel with you when you go to a different city. Each person will have only one telephone number, whether they are at home, office, automobile, hotel or fishing. The future PCS terminal will be more than just a voice telephone. It will offer voice, video, and data services all in a single terminal. This means that in addition to talking, you can use the PCS terminal for accessing your computer, or for that matter, any authorized computer, receive fax and e-mail messages, make video phone calls, and access video libraries. This issue is further discussed in the next subsection.

1.2 THE PROMISE OF ATM TECHNOLOGY

Asynchronous transfer mode (ATM) technology is a packet switching technology. The purpose of all switching techniques is to route data streams to specified network addresses. In traditional circuit switching, e.g. in the telephone network, the address, i.e. the dialed digits, are used to set up a dedicated wireline connection for that particular call. The message, i.e. the conversation, is carried on this dedicated wireline connection. In packet switching, the message bits and address are combined into a packet, and forwarded from node to node. Although packet switching has the overhead of including the address in every packet, it has been found to be more efficient than circuit switching for bursty data, such as is generated by a computer terminal. Circuit switching, on the other hand, is more suited for fixed rate of data generation, such as voice.

ATM technology [2],[3], has been proposed as the technology of choice for mixed data types. Fig. 2 summarizes the potential benefits of ATM technology. ATM is a packet switching technology with fixed-size packets of 53 bytes, called cells. The adoption of ATM technology promises to allow mixed data such as voice and video to be carried over the same network, instead of on separate telephone and LAN networks, as is done today. This will allow the deployment of multimedia terminals, incorporating voice, video, and data, to communicate with each other over a single switched network. By and large, video today is carried over non-switched broadcast networks such as TV stations, and cable TV. The possibility of switched video and switched multimedia service will allow services such as dial-up personal videophone, dial-up videoconference to any location, dial-up video libraries, and electronic town hall.

1.3 KSC APPLICATIONS POTENTIAL

Let us consider the potential impact of combining PCS and ATM technologies. As we noted above, PCS technology is targeted for universal access to mobile communications, and ATM technology is targeted for universal multimedia communications. Together, these two technologies will usher in a new era of mobile multimedia communications. The concept of mobile multimedia communications will make possible bold new services and applications not yet conceived. Some of the ways this could impact operations at KSC are considered (See Fig. 3).

One possible application is described by the title of the project. The possibility of universal wireless access to a switched ATM network will allow the deployment of tetherless multimedia workstations. In particular, intercomputer communication will incorporate a wireless front end. This means that a particular workstation may be placed anywhere, and will receive the appropriate level of bandwidth service, regardless of location. Cable plant changes would not be required following personnel moves. With today's technology, the hardwired cable network is designed to handle a predicted pattern of bandwidth demand. If the demand pattern changes following personnel moves, say for example if a CAD engineer interchanges office locations with a secretary, the cable plant has to be rewired to meet the new location of high demand. At the same time, the bandwidth resource previously deployed for a high demand location, will be wasted when the demand at that location goes down.

Availability of wireless multimedia can significantly impact the information flow required for shuttle and payload operations. Currently the information is stored in the form of OMI's on a database system such as SPDMS. At the site of the operations, the information is carried on paper or by voice on OISD. The availability of wireless multimedia, will allow video instructions for operations, fast wireless scheduling updates, and videoconference among operation personnel for problem resolution. With two-way wireless support for multimedia service, it becomes possible to deliver rapid video verification of operation closeouts, as well as live video monitoring of critical operations by remotely located expert personnel, e.g. firing room.

II. ATM AND PCS TECHNOLOGY BACKGROUND

In this section we will review some background material on the development of ATM and PCS technology, emphasizing some key features that will be important in their application to mobile multimedia technology. In the next section, we will evaluate the various technological options against the criteria posed by the applications outlined in Sec. 1. Section 2 may be skipped by readers not interested in many of the details.

2.1 DEVELOPMENT BACKGROUND OF ATM TECHNOLOGY

Traditionally, the telephone network has been circuit switched. For our purpose, what this means is that the destination address, is first presented to the network in the form of dialed digits. The network processes this information in a centrally located intelligence unit to set up an end-to-end link between source and destination. The message, i.e. voice signal, is then applied to this dedicated link and appears at the desired destination by virtue of circuit connectivity. This principle is summarized in Fig. 4.

In addition to so-called space switching described above, modern telephone networks also employ time-switching. Time switching depends on time division multiplexing (TDMA). In the context of the preceding discussion, we can visualize a TDMA network as shown in Fig. 5. Here, the address is processed by a multiplexor and a demultiplexor located at either end of the link. The multiplexor takes a number of message streams and places them on the link in time sequence as dictated by the address. Thus the address is translated into a fixed position in the time sequence for the corresponding message stream. The important feature to note is that the processing of the address is now distributed between two intelligence units (multiplexor and demultiplexor) on either end of the link. We see that as technology progresses, the trend is away from a central intelligence unit to a distribution of the intelligence and processing tasks.

Next, packet switching is considered. The conceptual operation of a packet switching network is shown in Fig. 6. In packet switching, the address and message are bundled together to form a packet, much as the message contained in a letter is bundled in an envelope with the address on it. The packet is forwarded from node to node in the network. At each node, the address is examined and a decision is made about which should be the next link for forwarding the message toward its ultimate destination. Thus, packet switching is an example of distributed processing, whereby the intelligence is distributed throughout the network.

The various technological options are thus seen as methods for managing access to the communication link. At a more fundamental level, it is the bandwidth of the link that the users are really demanding. The fundamental parameters of network design are the physical deployment of links, their bandwidth capacities, and the network intelligence to manage access to the links in a way that is fair to everyone. In traditional circuit switching, the physical access to the link is closely controlled by the network intelligence. But once the physical connection for link access is set up, communication can proceed with little help from the network. On the other hand, in ethernet, an example of packet switching, all nodes have physical access to the link, and a great deal of processing is required in each and every node to ensure orderly usage of the link, and delivery of the message at only its proper destination. It is in this context of links, physical access and intelligence location that we will set our problem.

It is well-known that circuit switching is efficient for fixed-rate data, such as voice, where the source generates bits at a steady rate over long periods of time. But circuit switching is not efficient for bursty data such as from a computer terminal, which typically produces long periods of idle punctuated by short voluminous bursts of data bits. Packet switching provides more efficient service for bursty data. For this reason, today we have a circuit switched telephone network for voice, but packet switched LAN's such as ethernet and FDDI for computer generated data communication. Meanwhile video or TV signals are carried over broadcast networks such as network TV or cable TV.

The next step in technology evolution comes from a desire to have a single network for all types of signal streams: data, voice and video. We noted above that voice is efficiently carried over circuit switched network, and data over packet switched network. What type of network should be designed for carrying a mix of traffic? This fundamental problem arises because of the wide disparity in the bandwidth demand of the different types of traffic. Data requires much less bandwidth than voice, which in turn requires much less bandwidth than video. A circuit switched network, including TDMA, assigns a fixed amount of bandwidth to all users. This means all users must be assigned as much bandwidth as those with the highest demand, leading to a great deal of wasted bandwidth resource. Circuit switching ends up assigning more than their fair share of bandwidth to users with low bandwidth demands. On the other hand, a packet switched network favors users with high bandwidth demand. Since packet switching is a random access technology, anyone can access the bandwidth resource. The low demand users will quickly release the resource for others to use. Not so the high demand users. Because of their greater needs, having once gained control of the link, they will retain control for longer periods of time, thus effectively locking out users with low demand.

In the ATM specification, the packet size is fixed as a resolution of the above problem. Keeping the packet size relatively small forces the high bandwidth user to give up the link more often, thus giving a chance for other users to access it. At the same time, too small a packet size reduces efficiency for the high bandwidth users, since the overhead cost of the address in the packet is incurred more frequently. The ATM specified packet size of 53 bytes is a compromise between the needs of users with low and high bandwidth needs.

2.2 ISSUES AND OPTIONS IN MOBILE COMMUNICATION TECHNOLOGY

Cellular phone communication for automobiles has been available for about a decade. A summary of cellular system concepts is given in Fig. 7. The cellular concept is to divide the geographical service area into circular regions called cells. All the mobile users in a particular cell are serviced by a single base station located in the center of the cell. All the base stations are linked through a switched network. The exchange servicing the network connecting the base stations is called the MTSO, or mobile telephone switching office. The links from the base stations to the MTSO can be land lines or high capacity point-to-point dedicated microwave links. The MTSO is responsible for overall supervision and control of the cellular network.

A fundamental concept in cellular system planning is the number of channel sets, usually 4 or 7. All available channels are divided into a fixed number of channel sets. Each cell site or base station is assigned one channel set, such that neighboring cells do not have the same channel set. An example frequency reuse plan with 3 or 4 channel sets is shown in Fig. 8. Since there is only a finite number of channel sets, there will be other cells in the system using the identical channel set. There is a fixed mathematical relationship between the number of channel sets and the smallest distance (as measured in terms of the cell radius) between cell sites using the same channel set. Clearly, the smaller the number of channel sets, the shorter the distance before the same channel set will need to be reused. An important capacity measure in a cellular system is the number of users/cell per MHz of allocated bandwidth. For example let us consider a cellular system with 24 MHz of bandwidth. Each mobile user is assigned a channel or frequency-pair for 2-way communication with his base station. Say the bandwidth required for analog FM voice communication is 30 kHz in each direction, for a total of 60 kHz. Thus there are a total of 24 Mhz/60 kHz = 400 distinct channels available. If the number of channel sets is 7, then each cell can support 57 users. The number of users/cell/MHz is 2.4. If the number of channel sets is reduced to 4, then each cell may support 100 users. Thus, fewer channel sets lead to higher service capacity.

Due to frequency reuse, for a user assigned to a given channel, there are other mobiles using the same channel, located in other cells with the same channel set. These mobiles will cause interference with the transmission from the user of interest. The amount of interference is larger if the cochannel users are located closer. If this interference is intolerable, the separation distance between cochannel users must be increased. The only way this can be done is to increase the number of channel sets, with a corresponding reduction in the number of users/cell that can be supported. This is the basic tradeoff seen in cellular system planning. The number of channel sets is a compromise between the desire to have low interference and the desire to have as many users/cell as possible. This is shown in Fig. 9.

When cellular phones were first introduced, the price was high and the demand low. Only a few large cells were required to service the demand. As prices came down, and the demand grew, it became necessary to introduce more and more smaller cells. This has led to the growth of the so-called microcellular systems technology. Microcellular systems are characterized by a large number of small cells, some as small as a city block. In the next generation PCS technology, the cells may be as small as individual floors in buildings. Each cell will be served by separate base stations. One issue under active investigation is the effect of small cells on hand-offs. Hand-off is the network action by which a mobile using a frequency in one cell, is automatically assigned a new frequency in the adjacent cell, as it moves from one cell to the next.

2.2.1 DIGITAL CELLULAR

Although cellular phone service has seen phenomenal growth in the last few years, there are a number of issues that need resolution. The most important of these is how to increase service penetration among the population, so cellular service begins to approach the universal accessibility envisioned in the PCS scenario. In general, the most obvious ways to increase service capacity in cellular systems are to convince the FCC to allocate more spectrum, or to build more, smaller cells. Initially, cellular service was based on analog FM modulation. Beginning in the 1990's, the industry has started a shift to digital modulation to increase service capacity without getting new frequency allocations from the FCC. Instead of modulating the carrier directly with the analog voice signal, the voice signal is first sampled and digitized, and the resulting bit stream is used to modulate the carrier. Digital modulation can be binary or M-ary. In binary modulation, only two waveforms are transmitted, representing binary 1 or 0. In M-ary modulation, the bits are grouped, and a group of $\log_2 M$ bits are used to select one of M different transmission waveforms. Use of M-ary modulation reduces the channel bandwidth requirement by a factor of $\log_2 M$. The two most widely used modulation options are GMSK, which is used in the European GSM system, and QPSK, which is used in the Japanese and North American digital cellular standards.

Digital modulation allows a number of advantages related to capacity and quality. Digitized voice can be processed by compression techniques to bring down the bit-rate to around 8 to 10 kb/s. This means that up to 3 users may be served in the 30 kHz bandwidth used by analog FM. The bandwidth requirement may be even further reduced by using bandwidth-efficient M-ary modulation. (However, use of M-ary modulation introduces the additional issue of power-bandwidth tradeoff, discussed later in this report.) Additionally, digitized voice may be protected against channel errors by FEC coding. This helps protect against errors in transmission which are unacceptably likely to occur in an unprotected channel, due to reflections from buildings etc. In fact, both the European and North American digital cellular standards do incorporate Viterbi coding. However, use of FEC does require additional bandwidth, as discussed below.

2.2.2 POWER-BANDWIDTH TRADEOFF IN DIGITAL CELLULAR

The power-bandwidth tradeoff is fundamental to all of the technological options being considered to increase the capacity in digital cellular systems. The power bandwidth tradeoff is a result of Shannon's equation. The maximum rate of information transfer, in bits/second, over a channel of bandwidth B is

$$R = B\log_2(1+\frac{S}{N})$$

where S/N is the signal-to-noise ratio at the receiver. For our purpose, we will use S/N interchangeably with C/I, the ratio of the received power of the signal carrying desired information, to the received interference power. C/I is sometimes referred to as CIR, the carrier to interference ratio.

For bandwidth efficient communication, to make it possible to serve the largest possible number of users, we would like to keep the channel bandwidth low. From Shannon's equation we see that for a given information transfer rate, we can reduce the channel bandwidth if we can increase the SNR. But we saw above, that in cellular systems, increase in the CIR comes from increasing the distance to the cochannel cells, which in turn reduces capacity. The precise effect of the power bandwidth tradeoff in digital cellular is still a subject of ongoing research [4]. The various technology options for enhanced capacity in digital cellular and the implications of the power bandwidth tradeoff are summarized in Fig. 10.

2.2.3 QPSK, CODING AND TDMA

As was stated above, QPSK has been adopted as the standard modulation scheme for next generation North American digital cellular. QPSK is 4-ary modulation, and therefore provides for a doubling of bit-rate within the same bandwidth. Thus it should be possible to transmit 60 kb/s over the standard 30 kHz analog cellular (AMPS) channel. However, from our discussion of the power bandwidth tradeoff above, it should not immediately be concluded that this alone will lead to increase in the system's service capacity.

The TDMA digital cellular standard also calls for coding. There are two forms of coding. The first is voice or source coding, and the second is channel coding. Source coding extracts the essential features of the information and represents them in fewer bits than when the analog signal is sampled and digitized. Source coding applies only to voice or video signals. When sampled and digitized, a standard voice signal requires 64 kb/s. Voice coding techniques such as ADPCM, LPC etc. can be used to reduce the bit-rate. The TDMA standard calls for use of LPC to reduce the bit-rate of voice signals to 10 kb/s. By the way, NTSC full-motion color video signal requires 76 Mb/s when sampled and digitized. Digital data compression techniques such as ADPCM, DCT, wavelet technique, etc. can be used to reduce the bit-rate of video signals.

FEC or channel coding is used to protect against errors in the transmitted signal induced by channel imperfections. Parity bits and CRC bits are two common forms of channel coding that allow for error detection but not error correction. More advanced types of channel coding allow for a limited amount of automatic error correction. There are two types of FEC coding: block and convolution. Convolution coding with Viterbi decoding is a widely used FEC technique. Use of FEC increases the number of bits to be transmitted. It would appear that this is undesirable due to increase in the required channel bandwidth. However, the principle of power-bandwidth tradeoff mitigates the bandwidth expansion by a corresponding reduction in the required CIR. Thus channel coding can be a benefit. The digital cellular standard calls for convolution coded FEC.

The new digital cellular standard uses TDMA. The users must take turns to use the channel in an orderly synchronized way. Nominally, the total channel capacity is 60 kb/s, and the bit-rate of raw digitized voice is 64 kb/s. When the effects of source coding, channel coding, the need for guard time between users, and the reservation of time slots for network control is all taken into account, it is seen that three digital users can fit into the 30 kHz bandwidth of one analog user.

2.2.4 CDMA, POWER CONTROL, VOICE ACTIVATION, CELL SECTORIZATION

CDMA has been proposed as an alternative to TDMA for digital cellular [1, p. 472]. The main benefit claimed for CDMA is that it will provide for 20 times the capacity of the analog cellular (AMPS) system. As noted above, the TDMA architecture provides for a tripling of capacity.

CDMA is based on the spread spectrum technology that the military has used for many years. There are two kinds of spread spectrum: Direct Sequence and Frequency Hopping. Direct sequence is more popular because it is easier to implement in practice. In DS-CDMA each user bit is converted into a specific long sequence of bits. The resulting string is transmitted using a simple modulation such as BPSK. The user specific sequence of bits is called the PN code. The length of the sequence is called the processing gain.

When CDMA is used, the transmitted bit-rate, and hence the channel bandwidth is increased by a factor equal to the processing gain. Because of the increased bandwidth, by the principle of power-bandwidth tradeoff, CDMA is able to operate with correspondingly reduced CIR. For example if the user bit rate is 10 kb/s, which is typical for compressed speech, a processing gain of 100 would lead to a transmission of 1 Mb/s. At the same time the required CIR can be reduced, say from 3 to 0.03. It is the reduction in required CIR that leads to a capacity benefit in cellular systems.

The CDMA system is designed to operate in an environment of many interfering users. All users use the same frequency band. Each user in a CDMA system is assigned a unique PN code. The receiver is tuned to a particular code. It uses a process called matched filtering to select the user of interest and reject other interfering transmissions.

In addition to the reduction in CIR, additional capacity enhancing features are used in the proposed CDMA cellular system. These are power control, voice activation, and cell sectorization. Transmitter power control is used so that transmissions from users close to the cell site do not overwhelm the weaker received signals from users farther away. Voice activation is based on the statistical observation that a typical voice signal is active only 38% of the time. Shutting off the transmitter whenever there is no speech signal present, reduces interference to the other users. Sectorization means that the circular cell is divided into three independent 120° sectors by the use of directional antennas. In essence, cell sectorization is like having three smaller cells, except that the hand-off between sectors can be handled locally, without interference by the MTSO.

It can be shown that out of the factor of 20 capacity benefit of CDMA, about a factor of 10 can be attributed to cell sectorization and voice activation, and only about a factor of 2 to the lower CIR. In general, it is difficult to improve capacity by applying the power-bandwidth tradeoff alone. In CDMA systems, the increase in channel bandwidth offsets some of the capacity gains obtained from the CIR reduction. On the other hand, in M-ary modulation, the increase in required CIR offsets some of the capacity gains obtained from the bandwidth reduction. The comparative features of TDMA and CDMA are shown in Fig. 11.

2.2.5 ALOHA AND PRMA

ALOHA is the protocol developed at the university of Hawaii for random access packet data communication [1, p.231]. It is inherently suited for bursty data sources such as computer terminals. It avoids the wasted bandwidth associated with the uniform division of bandwidth associated with such techniques as FDMA, TDMA, CDMA, etc.

Essentially, in ALOHA protocol, a terminal transmits a packet as soon as it is ready. The transmission succeeds if no other terminal transmits simultaneously. Because success is a random variable, this is also referred to as statistical multiplexing. A successful transmission is verified by the destination terminal transmitting an acknowledgment to the source. If a transmission fails, the packet must be retransmitted. The maximum utilization of the channel in ALOHA is 18%. Even so, this is an improvement over TDMA when the data sources are very bursty. An improvement of ALOHA is slotted ALOHA in which the time-scale is divided into uniform periods of length equal to one packet duration, called slots. Every transmission is constrained to start at the beginning of a slot. The maximum utilization in slotted ALOHA is 36%. A further improvement is carrier sense multiple access (CSMA), in which each terminal monitors the channel for any ongoing transmission, and defers its transmission until the current transmission is complete. CSMA is used in ethernet. Each improvement in channel utilization comes at the cost of increased complexity in the receiver. In general, packet communication networks use some sort of statistical multiplexing. This is also true for ATM. Statistical multiplexing performs well when the total network load is light, but the channel utilization drops dramatically when the network traffic is high, due to repeated collisions and retransmissions.

There has not been a great deal of attention devoted to packet communication in the study of cellular systems. This may be due to the fact that cellular service started with voice. In fact, even the voice market is yet to mature fully. The most noteworthy work in the cellular packet communication is the development of PRMA (packet reservation multiple access) [5]. Cellular packet communication is still a subject of ongoing research [6]. Outside the cellular context, packet radio networks (PRN) have been extensively studied [7] for their application to DARPA survivable radio network architecture.

We will restrict our attention to PRMA here. PRMA is a combination of slotted ALOHA and TDMA. Each PRMA frame consists of a fixed number of slots. Each slot can hold a single user packet of 44 bytes of payload and 4 bytes of address. Users contend for a slot by randomly accessing a vacant slot. If the base station successfully decodes a user's transmission in a particular slot, that slot is reserved for that particular user in succeeding frames, much like TDMA. The base station continuously broadcasts information about reserved and accessible slots in addition to down link data for users already connected. Each packet is also acknowledged by the base station. A user maintains control of his slot as long as he has data to send. When he has no data to send, he relinquishes control, and other users may contend for that slot. Due to statistical multiplexing, the number of users that can be supported can be larger than the number of slots. The exact number will depend on the burstiness of the data streams. For voice traffic, assuming voice activated transmission, there can be 1.6 users per slot [6].

III. DISCUSSION

In this section we will consider the technology options presented in Sec. 2 and evaluate them against criteria posed by the applications of Sec. 1 to develop a scenario for the development of mobile multimedia technology.

It is assumed that there will be a large number, possibly thousands, of wireless ports scattered throughout the service area, indoors as well as outdoors. Users are free to access these radio links anywhere, and demand variable amounts of bandwidth service, i.e. voice, data, or video. The goal is to service a shifting pattern of bandwidth demand in a way that the cost is proportional to the aggregate demand rather than the product of the peak demand times the number of ports. In other words, although each port should be capable of servicing the peak bandwidth demand, say for video, the actual network resource needed to serve the port should depend only on the instantaneous bandwidth demand, be it voice, video or data. ATM networks have this feature.

3.1 ISSUES IN MOBILE MULTIMEDIA

Following is a potential list of issues for discussion:

1) Granularity. How close should the ports be located?

2) Access method. TDMA, CDMA or ALOHA based.

3) Modulation and coding method.

4) Intercell network.

5) ATM adaptation. Whether packetization should take place in the terminal or in the base station.

6) Service capacity per port

7) Operation flexibility. How will a shifting demand pattern be serviced?

8) Spectrum. How much bandwidth will be needed, and where will it come from?

9) Cost

10) Technology development timeline

3.1.1 GRANULARITY, BANDWIDTH AND CAPACITY

The answers to these three issues are intimately linked. The number of users per cell that can be supported is fixed by the spectrum available, and technology choice e.g. CDMA, PRMA etc. Of course, users can have variable bandwidth demand, so by the word user we mean a fictitious user with average bandwidth demand. Once the number of users per cell is fixed, the number of cells required is fixed by the total demand in the service area. If there is enough bandwidth to support 40 mixed service users, we may designate one port per wing in an office environment. If the number of users per cell drops to 10 we may need a base station in every room. The smaller the cell size, the less the bandwidth as well as power required. Thus smaller cells have a practical advantage. In theory, smaller cells would require closer management by the network as the demand moves from cell to cell.

As demand moves around, it is possible that there will be a demand imbalance from cell to cell. To address this imbalance, it is proposed here that the intercell network be an ATM switch. The traditional MTSO and cell planning which treats each cell equally and assigns equal bandwidth to every cell are not desirable.

3.1.2 ACCESS METHOD AND ATM ADAPTATION

This issue should be clear to the reader by now. A review of the path taken by switching technology and the trends seen in cellular technology suggests that many of the mistakes of switching are being repeated by cellular. Switching technology developed with only voice in mind, and had to go through a radical rethinking when data applications proliferated. The same trend is now seen in cellular. The big debate in cellular is whether TDMA or CDMA is better for capacity. It is proposed here that both are methods for dividing capacity equally among users, and are suited for voice, not data. Mixed media service will require a packet based technology. It could be PRMA, or some other technology yet to come. The choice of packet technology for cellular use is still an active research area. Some lessons learned for packet radio applications in DARPA may come in useful for this.

The above discussion also addresses the issue of ATM adaptation. Since the PCS scenario envisions a variety of terminal with varying bandwidth demands, it is essential that the access to the radio port be packet based. Thus packetization should take place in the terminal, not the port.

3.1.3 COST

All the technology needed for a multimedia terminal is available today. It would most likely combine a notebook PC, a miniature video camera, a packet network interface, similar to an ethernet card, and a radio such as in a cellular phone. All of these items can be purchased today for a total cost of $4000. The cost is likely to come down as the product is integrated and mass produced. Based on the price trends seen in PCs, we can estimate that the cost would be around $1000 in about 5 years.

3.1.4 TECHNOLOGY DEVELOPMENT TIMELINE

The real challenge in mobile multimedia technology will be to develop the network. This will have to go through a lengthy and complicated process. First, the architecture has to be developed further, and then standardized. This could involve a fairly long process of negotiation between vendors, regulating agencies, and standardization bodies. Based on the experience with digital cellular standard, we can guess that this will take about 5 to 7 years. After this, the network will have to be deployed. Based on the experience with recent products such as PCs and cellular phones this is a more rapid process and may take anywhere from 3 to 5 years. Therefore, we should start to see prototypes in about 5 years, and widespread deployment in 8 years.

3.1.5 RF SPECTRUM USAGE AT KSC

An important issue is how much bandwidth will become available for mobile multimedia technology. This is very much affected by how the RF spectrum is currently being used at KSC, and the possibility and cost of interference with critical operations. For this reason a short review of RF usage at KSC is included.

The primary operational communication systems, *viz.* OISD and OTV are not based on RF. Mission critical communication is often carried on land links in order to increase reliability. Where wireless techniques are conceived for mission critical operations, suitable error protection such as CRC or FEC should be included for reliability. Wireless communications are primarily used for communication with the orbiter itself. This includes telemetry, voice, data and video. The communication is carried in the S-band (2.2 GHz) and Ku-band (15 GHz) using 80 Mhz of bandwidth. The Ku-band is used when the vehicle is in orbit, while the S-band is used during ascent and descent. In base operations, RF is used for emergency communications such as police and fire rescue. These communications are carried out in the 150 Mhz, 400 Mhz and 800 Mhz bands, each 20 Mhz wide. KSC must share the frequencies reserved for government use with other government agencies in the area.

As technology progresses, new methods to utilize the spectrum more efficiently become available. To implement these requires a consensus with entities holding existing claims to the spectrum. Finding spectrum for new applications is not so much an issue of taking it away from existing stakeholders, as it is of finding new ways to share it for maximum benefit to the community as a whole.

IV. CONCLUSIONS

A review of ATM and PCS technologies shows that mobile multimedia technology could offer benefits at KSC in operations as well as in ground support. Current trends in cellular system technology are driven by the voice market rather than multimedia. Significant effort will be required in the development of network technology to support mobile multimedia. A shift toward packet based cellular communication will make mobile multimedia possible. Prototypes costing around $1000 are possible in about five years, and widespread deployment in about 8 years.

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PROMISE OF PCS TECHNOLOGY

PCS: PERSONAL COMMUNICATION SYSTEM

- Same phone anywhere -- home, office, car.
- Tetherless access
- Global roaming
- Access to custom terminal environment from any point in the network
- Multimedia services -- voice, fax, data, video
- Lightweight, portable terminal

Fig. 1. Promise of PCS Technology.

PROMISE OF ATM TECHNOLOGY

ATM: ASYNCHRONOUS TRANSFER MODE

- Packet switching based technology
- Mixed services -- voice, video, data, on single network
- Multimedia services
- Dial-up video library
- Teleconference and video intercom
- Electronic town hall

Fig. 2. Promise of ATM Technology.

KSC APPLICATIONS POTENTIAL

- Tetherless workstations. No cable plant changes. More flexible deployment of bandwidth.
- Two-way wireless multimedia support for operations.
- Video instructions and scheduling
- Fast wireless video closeouts
- Video conference to/from mobile locations

Fig. 3. KSC Applications Potential.

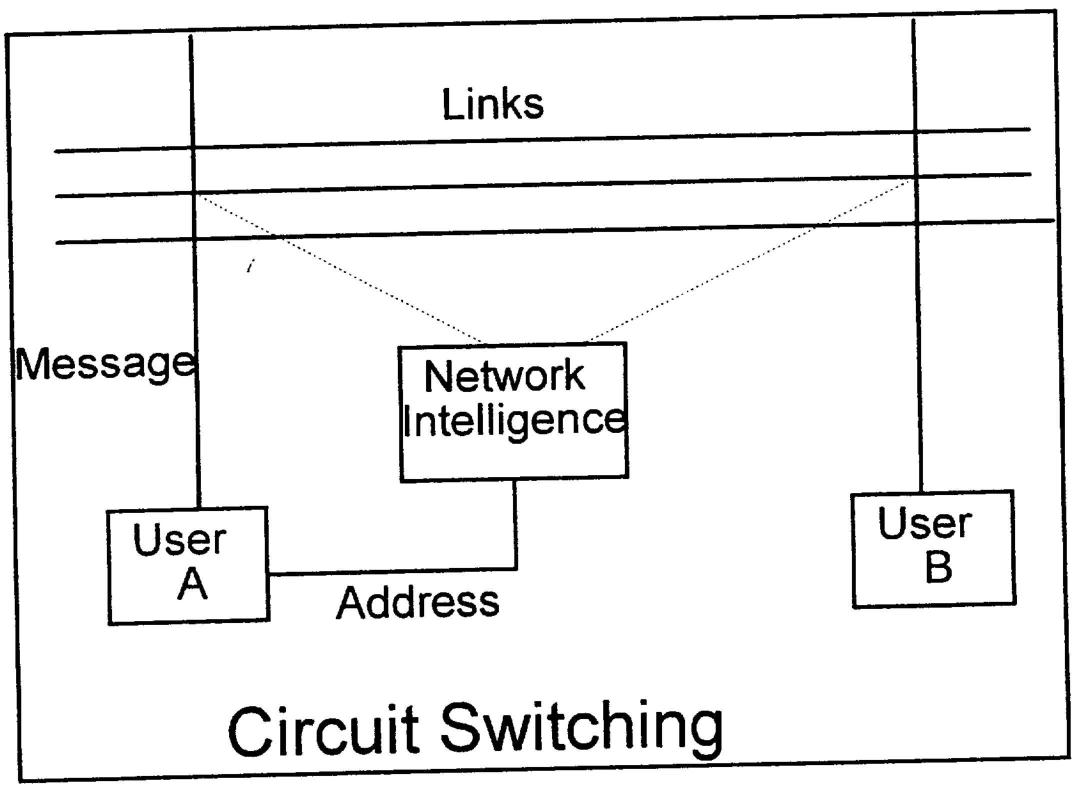


Fig. 4. Circuit Switching.

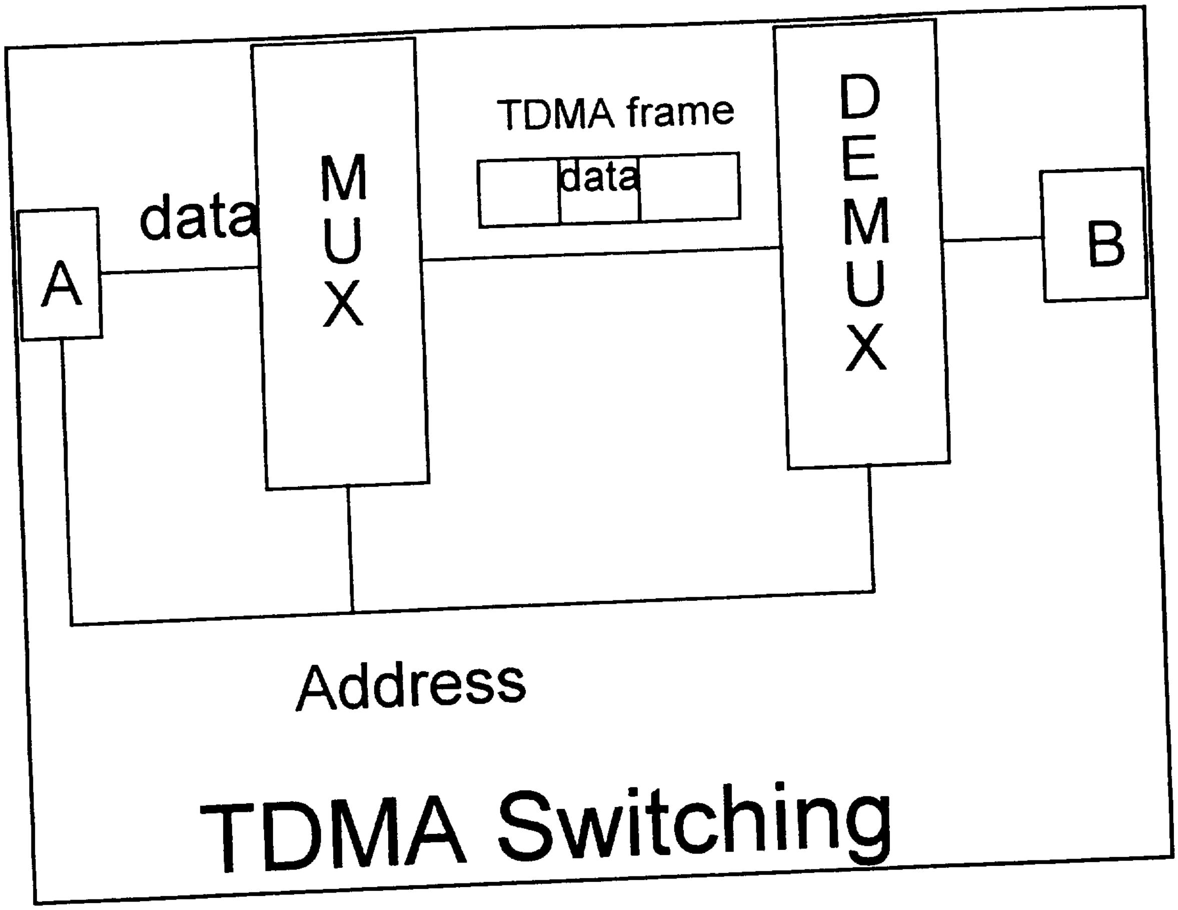


Fig. 5. TDMA Switching.

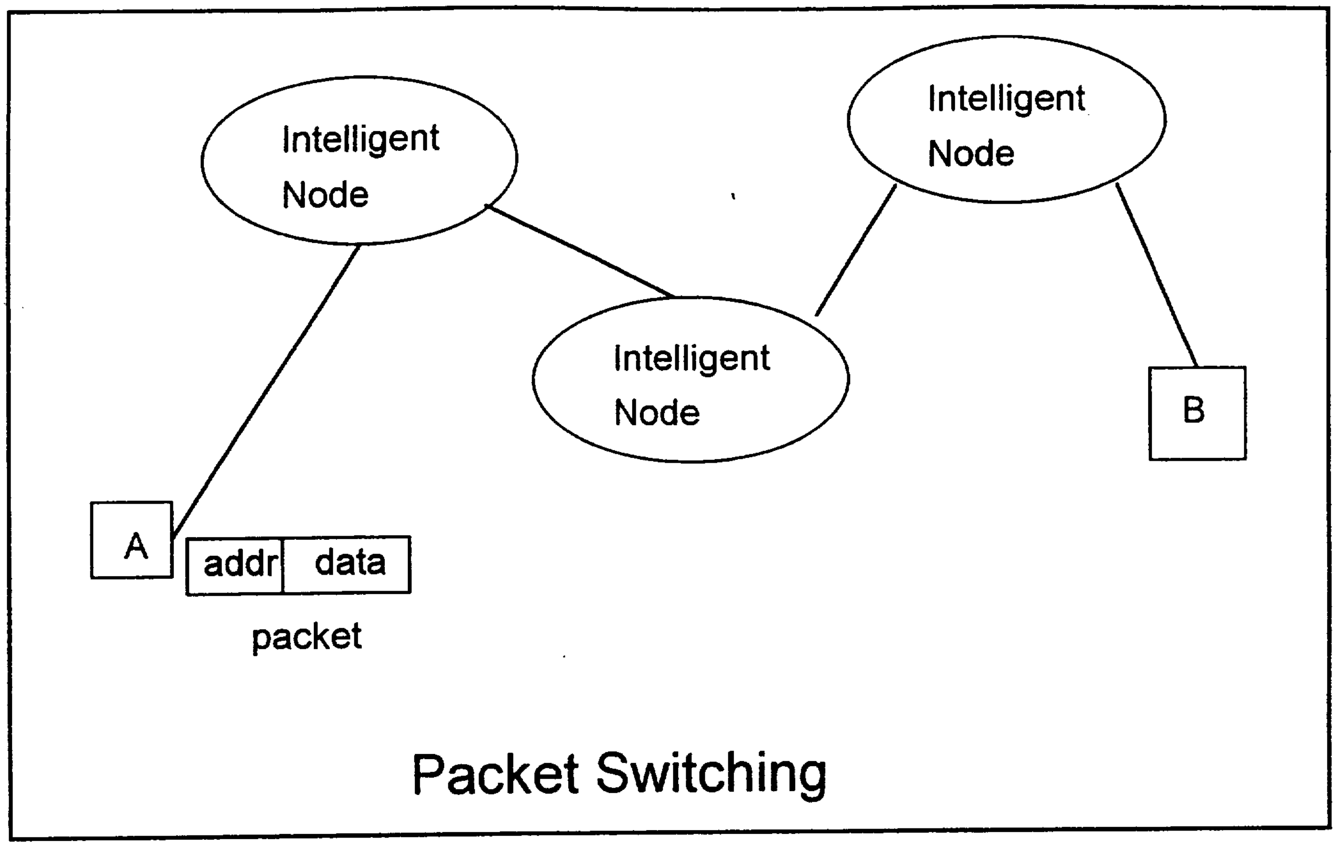
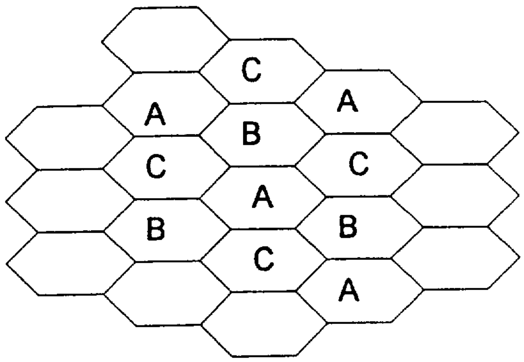


Fig. 6. Packet Switching.

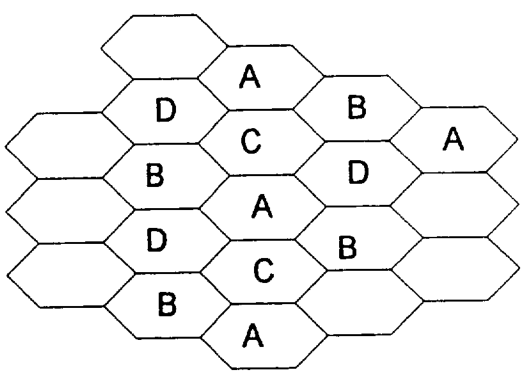
CELLULAR SYSTEM CONCEPTS

- Basic concept: Divide service area into circular cells. Assign channels to cells; neighbor cells do not have same. Reuse of channel in other cells.
- Channel : User's set of assigned frequencies for 2-way comm. within the cell
- Cochannel cell: Where the same channel is being reused
- Reuse distance: Smallest distance between cochannel cells
- Cochannel interference
- Capacity grows as inverse of reuse distance
- Interference also grows same way
- Key problem: How to increase capacity but not interference.
- Hand-off : Automatic assignment of new channel as mobile moves from one cell to another
- Base station or cell site : Radio port to land-based network, one for each cell.
- MTSO : Mobile telephone switching office. Switch for intercell communication.

Fig. 7. Cellular system concepts.



THREE CHANNEL REUSE PATTERN



FOUR CHANNEL REUSE PATTERN

Fig. 8. Example of 3- and 4- channel reuse patterns.

CELLULAR SYSTEM PERFORMANCE

- **Performance Measure : number of users per cell.**
- **Lee's formula:**

$$m = \frac{B_t / B_c}{\sqrt{\frac{2}{3}\frac{C}{I}}}$$

where m = **users per cell**
B_t = **Total system bandwidth**
B_c = **Channel bandwidth**
C/I = **Worst case CIR (Carrier to interference ratio). Varies directly as reuse distance.**

Fig. 9. Cellular system performance.

CAPACITY ENHANCING TECHNIQUES

Method	BW	CIR (Reuse dist)
Voice compression	dec	none
Error correction	inc	dec
M-ary mod. (QPSK)	dec	inc
CDMA	inc	dec
Sectorization	none	dec
Voice activation	none	dec

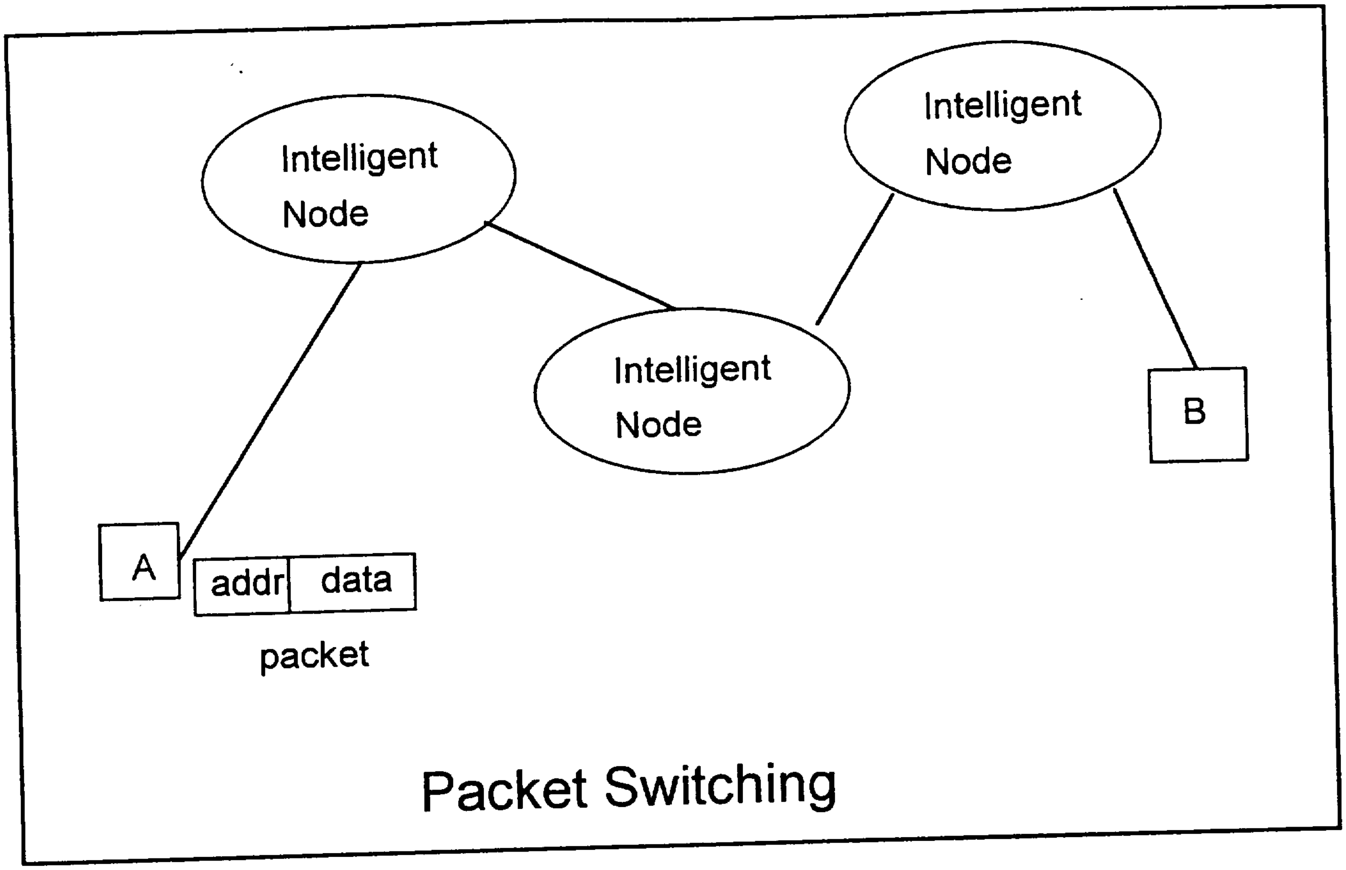
Fig. 10. Capacity enhancing techniques for digital cellular.

PROPOSED DIGITAL CELLULAR STANDARDS

TDMA
- QPSK modulation
- Source coding (LPC)
- Channel coding (convolution)
- Triple AMPS capacity

CDMA
- Spread spectrum technique
- Cell sectorization
- Voice activation
- 20 times AMPS capacity

Fig. 11. Comparative features of TDMA and CDMA.



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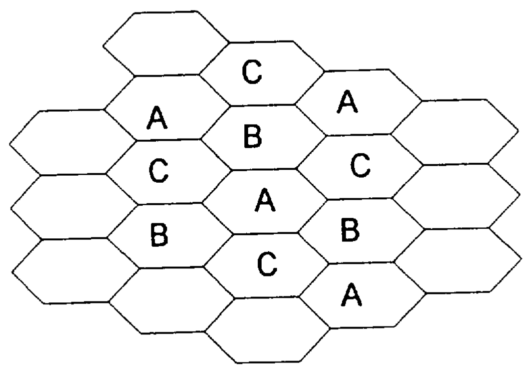

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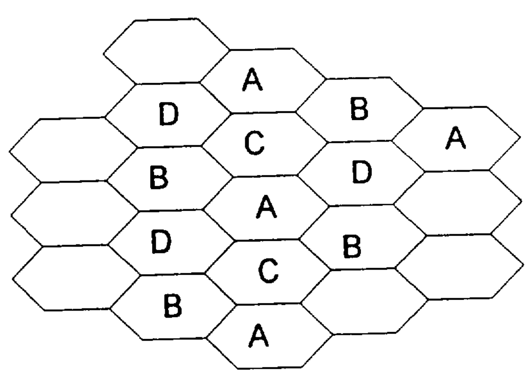

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