Potential Role of Spread Sprectrum in a Specific ATIS

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1. BACKGROUND

The *Dynamic Vehicle Route Guidance System* pursued by Siemens (AliScout or EuroScout) utilizes Vehicle Roadway Communications (VRC) at selected points in the covered area; these VRC sites are often (but not necessarily) at intersections. This limited-effort project investigated the potential benefits of using spread spectrum (SS) communication links for the following three separate applications within that system:

I. FILL-IN LINKS OF THE MESH-NETWORK BETWEEN VRCs AND TAC

In some situations a telephone connection is not convenient or nearby for the VRC to Traffic Advisory Center (TAC) infrastructure link. This data link needs continuous connectivity of at least 9600 bps and can utilize dedicated leased-line telephone voice circuits when available and cost-effective. Presumably this fill-in data link should be full duplex and the control algorithms should be of the circuit-switching variety. Two natural candidates are (conventional) short range (few miles) microwave and SS.

II. ALTERNATIVE TO THE USE OF IR FOR THE VRC

The VRC in the present system is done via an infra-red (IR) beacon, under the control of a *Beacon Site Controller*. This method can effect a relatively narrow space window (volume) in which the communication can occur. A VRC based on microwave, either conventional (non-SS) or spread spectrum, would offer a larger communication zone with slightly less stringent line-of-sight (LOS) restrictions (due to better shadowing) but would require a reliable multiple-access protocol to permit the near simultaneous conversations in the larger zone to succeed.

For cost-benefit purposes it is important that a common technique and frequency be used for the entire set of IVHS, short-range, vehicle- to-infrastructure connectivity. Thus, the choice of VRC for the specific ATIS here should be influenced by this universality goal.

The data rate using the IR link would be 500 kbps; with a larger zone that accompanies any use of RF, the data rate might be reduced some, but is expected to be relatively high. For the overview purposes here we will assume a data rate of about 250 kbps (or higher) is required. The control protocols would be packet-based for this VRC link.

III. INFRASTRUCTURE CONNECTIVITY BETWEEN ADJOINING VRCs

Consideration is being given to offering the driver a "route look ahead" feature, which requires rapid and selective communication between a given VRC and adjoining ones. Although not part of the present system, this envisioned feature might utilize beamed or unbeamed RF connectivity directly to the adjoining sites. This approach would be in competition with simply using the ubiquitous telephone network for the connectivity. If the direct RF approach were used, the two natural candidates again are short-range microwave and SS.

2. OBJECTIVE

The specific objective of this effort was to examine and evaluate SS modems and networks for each of the applications noted, compared with the natural alternative of using short range microwave (or IR) links.

3. GENERAL OPPORTUNITIES AVAILABLE WITH SPREAD SPECTRUM

The essential concept in spread spectrum is to introduce complexity with the objective of obtaining some desired communication advantage over traditional techniques. SS originated in military communications, but is currently being pursued for civilian systems [1] such as in the applications here.

SS is applied almost solely to digital (or data) signals, as opposed to analog signals, in the general manner indicated in figure 1. The SS modulation is either direct sequence (DS) or Frequency Hopping (FH). With DS, the spreading stems from use of a pseudo-noise (PN) sequence having a "chip" rate much higher than the encoded information bit rate, as sketched in figure 2; both the time and frequency domain are shown. With FH, the spreading stems from a rapid hopping among a wide range of freqeuncies, as depicted in figure 3, which shows the general frequency versus time behavior. In this case the PN sequence acts essentially as a random number generator.

While the military applications of SS often stress *antijam* and *low probability of intercept* objectives, the civilian applications only indirectly involve these goals. We will now review the general nature of the opportunities and features offered by SS in civilian applications.

First, we note that SS is an RF technique; it appears to make no sense to apply it to IR or any other optical links. Also, at RF, whether or not one uses SS does not affect the essential propagation loss at the particular RF frequency. Typical propagation path scenarios are considered to be: essentially flat surface; flat surface with foliage; interleaving rolling hills; interleaving mountains.

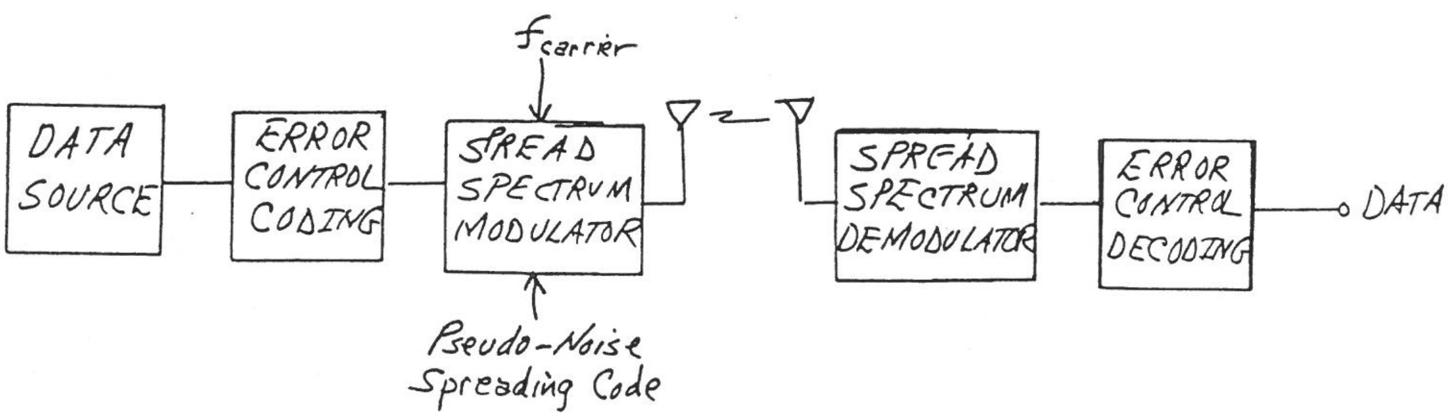


Figure 1 Spread Spectrum Concept

Figure 2 Direct Sequence S. S.
Pseudo-Noise (PN) or Direct System

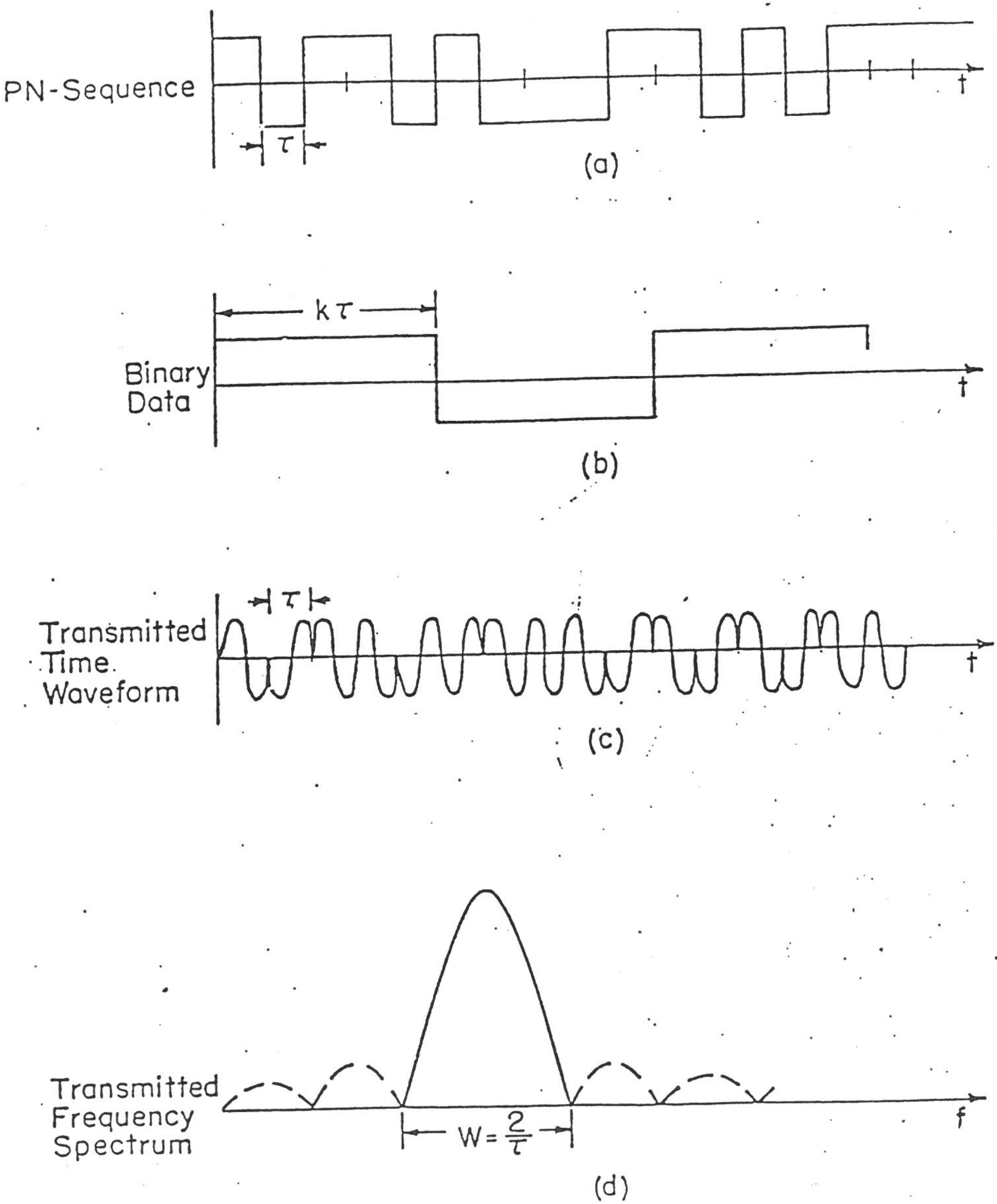
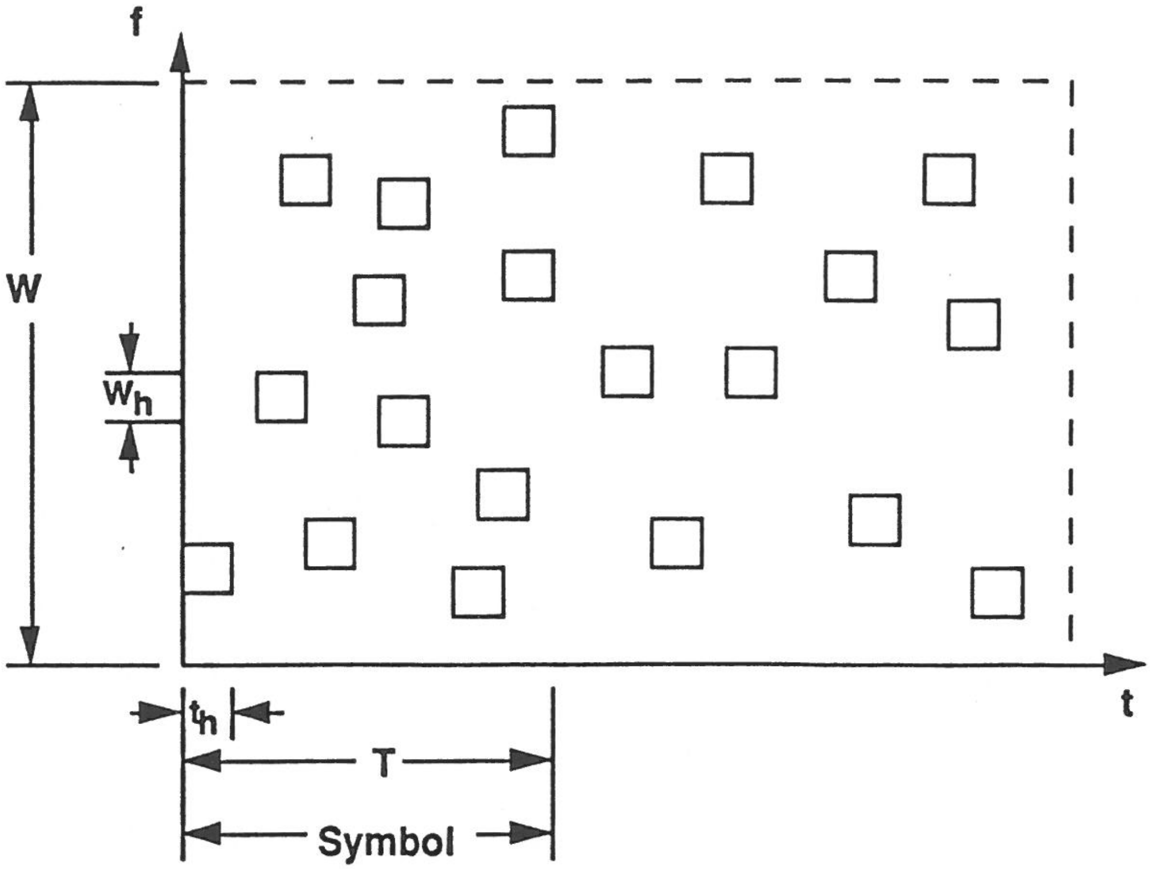


Figure 3 Frequency Hopping (FH) Systems
PN Sequence used as a Random Number Generator



The opportunities in civilian applications for SS fall into the following categories.

3.1 NEW PARADIGMS FOR SHARING SPECTRUM--CODE DIVISION MULTIPLE ACCESS(CDMA): For communication link distances exceeding a few hundred feet, the traditional approach to sharing spectrum has been to allocate the various regions of spectrum to the various competing users via *licensing* by the FCC, giving each user only that bandwidth that is required for that service so as to be able to maximize the number of users. This*minimum bandwidth* approach has been used, along with frequency-reuse over space, to organize the sharing of spectrum by the various competing users of the resource. Note that this *minimum bandwidth* allocation philosophy also covers the case where the overall user has multiple subusers and may use time division multiplexing (TDM) to distribute the allocation among the subusers.

For exceedingly short communication distances, where the bother and cost of licensing is not justified, certain spectrum regions have been set aside for unlicensed operation and, traditional unlicensed operation has limited the permitted transmitter power to very low values (50 mW or less) so as to constrain the range of the emission. This is the approach used for garage door openers, animal tracking, radio controlled toys, cordless telephones, wireless microphones, security alarm applications, etc.

SS has permitted pursuing a different approach for sharing the spectrum: defining a relatively broad frequency swath, and then having a relatively large number of users in that spatial area share the allocation with no formal (organized) control of access to the frequency region. This SS approach is referred to as code division multiple access (CDMA), and can be implemented with either DS or FH (although DS seems to be preferred).

The new paradigm offered by SS with CDMA has thus far had its greatest impact in the unlicensed (Part 15) arena. Although prior SS FCC items appeared under Part 15.126, in May 25, 1990 the FCC adopted Part 15.247 (see Appendix A) which retained the essential specifications of the earlier version but delineated more specific procedures for the measurements that demonstrate equipment compliance with the emission specifications. The significant issue of the Part 15 SS is that the allowed transmitter power is greatly increased: from the order of 50 mW to 1 Watt. This substantially increases the range of effective communication and hence increases the potential applications for Part 15 operation.

The frequencies allocated under Part 15.247 are 902 to 928 MHz, 2400 to 2483.5 MHz, and 5725 to 5850 MHz. Specific rules apply to details of the SS signal in each region. In the 902 to 928 MHz region the 6 dB bandwidth of any Direct Sequence signal must be at least 500 KHz. The 1 W power limitation applies to an omnidirectional antenna; for antenna gains above 6 dBi the power has to be lowered correspondingly.

As in all Part 15 operations, the user bears the responsibility both for not interfereing with other licensed or unlicensed operations, and for solving any interference problems that are encountered. Thus, while Part 15 offers flexibility and freedom from having to obtain lenghty FCC approvals for licensed operations it also places the responsibility for proper operation on the user. Whereas any licensed operation relies (eventually) on the FCC to resolve any developed interference, with Part 15 the user bears both the risk and the responsiblity for such resolution.

The unusually large bandwidth nature of the SS signals offers opportunities for dealing with developed interference if it is significantly narrower in bandwidth (than the SS signal). Techniques such as notch filters can be used to greatly attenuate narrowband interference while only modestly degrading the SS signal performance.

Thus far the unlicensed (Part 15) application of CDMA has been applied mainly in wireless local area networks (LANs). The largest number of SS suppliers have addressed the LAN market; another niche being pursued is that of using beamed or unbeamed links to form ad hoc networking (as we shall see).

While the unlicensed operation in the designated SS bands has seen the most SS action to date, there is some hope that SS signals might also be used in spectrum (microwave) regions overlaying licensed (usually beamed) systems. If both the licensed and the SS application are fixed-point, then there exists the possibility that the SS signal can coexist in frequency with the licensed non-SS signal; the sensitive parameter would be the distance of the SS transmitter from the licensed receiver. If such SS applications would provide negligble interference to the licensed one, then the spectrum availability for SS applications would be greatly increased.

3.2 MULTIPATH RESISTANCE: A second major aspect of SS is its influence on multipath. It is well known that in any mobile application, where either the transmitter or the receiver or both are mobile, signals of conventional bandwidths (25 KHz) suffer Rayleigh fading due to the effect of multiple-paths between the transmitter and the receiver.

Since the different paths have at least a small difference in time of arrival, large increases in signal bandwidth diminish the chances for multipath signals to degrade or cancel each other. The major effect is that, with the wide bandwidth signals, the two arriving signals appear separated in time. Hence, the first multipath benefit of the wide bandwidth signals is that the receiver can "lock on" to one of the arrivals (the direct one) and essentially ignore the other arriving signal(s). This is referred to as *multipath resistance* since one prevents most of the degradation otherwise encountered with multiple arriving signals and 25 KHz bandwidths.

If cost-beneficial, one can actually exploit wideband multiple arriving signals by *coherently adding* the arriving signals using a technique referred to as a *RAKE receiver*. While RAKE reception is complex and potentially costly, if implemented by application specific integrated circuit (ASIC) technology it may become feasible for mobile communication application.

3.3 RANGE EXTENSION: A third SS aspect of interest in civilian (and military) applications is that the SS signals are superior candidates when one wishes to increase the range of a communication link by using *coherent integration of received power*. One trades off data rate for increased range, for a given transmitted power. This is referred to as exploiting the processing gain available with high time-bandwidth signalling. In theory, one could trade data rate for range with ordinary (non-SS) signalling but SS makes it more feasible to implement in practice since, for a given processing gain, a higher data rate can be retained.

3.4 INCREASE IN PRIVACY: The spreading code used in spreading the spectrum serves as a vehicle for increasing the privacy of the tranmsitted signal. It should be noted that digital signals themselves have an elementary degree of privacy since they require a digital receiver for "reading" the signal, especially if it is embedded in a time-multiplexed stream. The SS contribution, then, is an addition to this elementary privacy component.

3.5 POSITION-LOCATION COMPATIBILITY: Signals having a large bandwidth offer the maximum capability for implementing passive position location techniques to position fix an emitter. The autocorrelation produced by a matched filter receiver has a width inversely proportional to the bandwidth of the signal, which produces an increasing accuracy for *ranging* as the bandwidth increases. The ranging, at two or more receiving sites, can be used for position location.

4. CANDIDATE SPREAD SPREAD EQUIPMENT

The following SS equipment was selected for consideration here because 1) they have been widely advertised, and 2) they appear applicable.

4.1 TELESYSTEMS: ARLAN 100 AND ARLAN 400 SYSTEMS

Telesystems has been offering wireless LAN SS products since approximately 1988 and is perhaps the first significant vendor of SS products for civilian use using the Part 15.247 in the 902-928 MHz range. The SS transceivers used in either the ARLAN 100 or the ARLAN 400 can be used in a single data link application, of interest here.

The Arlan 100 supports RS232C asynchronous data in the range of a system data rate of about 250 to 300 Kbps rate [3] since this must be shared by all the users, a single terminal may have a data rate in the order of 19.2 Kbps [4], depending on the size of the LAN. The link data control protocols are packet-based and the access protocol is CDMA.

With an antenna on a 30-to-40 foot pole, such as a standard telephone pole, the ARLAN transceivers can operate LOS for a few miles [2]. Any tall building in the path will block the signal so an obstacle-free path must be found.

4.2 HUGHES AIRCRAFT CORP: HUGHES NETWORK RADIO (HNR)

The Hughes Network Radio (HNR) is the result of Hughes applying its extensive experience in military spread spectrum systems to the civilian market. (In prior Hughes literature this product series was referred to as "Spread Spectrum Radio Network."

The HNR is a comprehensive approach to networking transeivers in a metropolitan setting and is "designed to provide the communications infrastructure for transmitting sensor and other data to an operations center, and returning command/control data to the remote network controllers." [5]. It can operate as stand-alone data linkage or as a comprehensive network that is almost entirely automated. HNR is perhaps the first comprehensive offering that considers both traffic- management systems, involving both gathering traffic data and controlling traffic lights, and delivering downlink information from a traffic central to roadside (or other) delivery points.

Hughes offers a modem that can cover 5 miles (omnidirectional) at 9600 bps; another model offers 242 Kbps, a 3-MHz bandwidth, at a range of one mile. Any of these parameters are changeable relatively easily, where one can trade data rate for range. The linkage uses Part 15.247 operation in the 902-928 MHz region. The intent is to provide a high throughput network within a metropolitan area that can be more cost beneficial than a network formed from either point-to-point microwave or a network based on broadcast radio (conventional or trunked microwave).

The HNR appears unique in that it implements protocols that provide the user with *transparent networking*. "The network automatically configures to any geographical topology and will automatically configure in the event of a radio or link outage" [5].

While the data rate is not specified per se, the linkage supports 128 Kbps compressed video, so the link rate probably is about 240 Kbps. The network is flexible so that single links or subnetworks of multiple links can be organized. Its earliest availability is expected to be Oct./Nov. 1992 [6].

4.3 QUALCOMM Inc.: SS Systems using CDMA

QUALCOMM has been a leading and outspoken advocate of SS and CDMA, and has developed equipment both for an existing satellite tracking system (OmniTRACS) [7] and for a proposed digitial cellular system. One of the transceivers for OmniTRACS uses a 1 MHz bandwidth, but has only a low (55 to 165 bps) data rate. It is not clear what, if any, of the OmniTRACS equipment is applicable here, but the general capability of QUALCOMM in SS as evidenced by this product is germane. Note that this is a licensed application of SS.

QUALCOMM is also pursuing CDMA as an alternative to the TDMA (proposed by the telephone industry) for implementing digital cellular (which also is a licensed application). In certain large cities the present analog cellular systems are running out of spectrum space due to increasing customers. Digital cellular can handle more voice signals per spectrum bandwidth than analog and is therefore a logical move for all areas where capacity is beginning to be limited. Currently there is a hot debate concerning the TDMA and CDMA approaches for digital cellular. Both approaches are being pursued into large demonstrations, and installations for both are planned. Some parties claim that TDMA will be an interim method, snd CDMA will be the subsequent generation.

QUALCOMM's CDMA uses a 1.25 MHz bandwidth Direct Sequence SS transceiver. The data rate for digital cellular (8 Kbps) is sufficiently close to the 9.6 Kbps needed for the fill-in link that it is candidate equipment. The QUALCOMM transceiver is relatively sophisticated in its cellular application, and it is not clear how much of that sophistication would be applicable here.

5. SPECIFIC SPREAD SPECTRUM ASPECTS FOR THE APPLICATIONS HERE

Overall, the major potential advantage of SS for the three applications of interest here appears to be the ability to install either fixed point links (#1 and #3) or very short-range mobile links (#2) without needing to plan for, take data for, and go through the ponderous FCC license application.

The corresponding major disadvantage is that the "user bears the responsibility for dealing with the interference." Thus, one must assume responsibility for not interfereing with a licensed (or unlicensed) user, and must be able to withstand interference from any other licensed or unlicensed source (until a resolution can be found).

We will discuss the SS aspects for each application in turn.

5.1 FILL-IN LINK: The natural alternative to SS here would be to field a licensed short-range microwave link. Hence, the major advantage seems to be the flexibility and ease afforded by avoiding the FCC application routine mentioned above. The use of SS offers the possibility of, in a quick-reaction fashion, installing a needed fill-in link. An assessment would have to be made to assure that no existing service would be interfered with.

If one looks to the future, it is possible to see that some new licensed or unlicensed interferer could degrade the performance of the installed system. In this case the alternatives are 1) use the interference-resistance of the SS to cope with the new interference; 2) increase the processing gain somewhat by reducing the data rate (note we need only 9.6 Kbps, but higher rates may be available); 3) add some error-correcting code (or strengthen an existing one), which also requires a reduction in data rate; and 4) move to a licensed microwave link. If the original installation allows for future increases in interference by using a data rate higher than the minimum needed, then one can, in the future, increase the processing gain by reducing the data rate.

The issue of multipath does not appear influential in this fill-in link application, since it is fixed point. It does not appear feasible to try to exploit multipath from reflectors of opportunity composed of buildings.

The range extension appears to have importance here, since it is the technique involved in trading range for data rate. In effect, the SS offers a degree of flexibility not usually present in the traditional non-SS signals, although fixed-point (non-SS) microwave systems would have plenty of bandwidth for the application here.

The privacy aspect appears to be a useful but perhaps not critical contribution in this application. The contribution to precise ranging and position location does not appear useful here.

The equipment of each of the three vendors covered in section 4 appears applicable here.

5.2 VRC: In this application a SS signal could be used with either CDMA or TDMA as the multiple-access protocol. Probably the most important factor for this link is the need to be consistent with "all the rest of the IVHS short-range communication applications." Since many VRC applications require multi-lane coverage at speed, this appears to be a requirement. Presumably at some future time all parties will gravitate to a single, short- range RF technique, and SS is likely to be a part of that scheme.

For the distances involved in the VRC, multipath does not appear to be a significant issue [9]. Also, range extension, privacy, and position location do not appear applicable here.

While the equipment of all three vendors should be considered here, it may be noted that Hughes [10] has devoted the most effort to pursuing a VRC, using a slotted Aloha TDMA multiple-access protocol.

5.3 ADJOINING VRC LINKS: This application, like the previous two, will profit from the relative ease of installing links in a quick reaction fashion, relative to non-SS, short-range, microwave links. The other general features of SS do not apply here, as was true for the first application.

The networking operation for this application is packet based, and half-duplex operation may be satisfactory. While the equipment from each of the vendors should be considered, it may be noted that Hughes Network Radio may represent the most advanced candidate for this application, due to the sophisticated network algorithms.

6. RECOMMENDATIONS

To prove out the general potential identified here, it is recommended that each of the vendors be contacted and provided the information here. Then, pursuant to technical exchanges with each vendor, action should be taken to test and demonstrate one or more of the SS devices for any of the applications that continue to show promise.

7. REFERENCES

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6. Private conversation with George Vardakas, Hughes, May 13, 1992.

7. Jacobs,I., and Salmasi,Allen, *The Application of a Novel Two-Way Mobile Satellite Communications and Vehicle Tracking System to the Transportation Industry*, IEEE Transactions on Vehicluar Technology, February 1991.

8. Salmasi,A., and Gilhousen,K., *On The System Design Aspects of Code Division Multiple Access (CDMA) Applied to Digital Cellular and Personal Communications Networks*, in IEEE Conference Record, CH2944-7/91/0000/0057.

9. Degauque,P., et al, *Beacon-Vehicle Link in the 1-10 GHz Frequency Range*, Advanced Telematics in Road Transport, Elsevier, Amsterdam, N.Y.,Oxford, London 1991, p. 194.

10. Series of announcements in *Inside IVHS*, *The Intelligent Highway*, and other IVHS newsletters about the Hughes VRC efforts.

APPENDIX A

The transceiver operates in the 902-928 MHz industrial/scientific/medical band, which has been assigned by the FCC for unlicensed use by spread spectrum systems.

"Spread spectrum communications systems use special modulation techniques that spread the energy over a very wide carrier by some conventional technique as AM, FM, or digital, and the bandwidth of the signal is deliberately widened by means of a spreading function. The spreading technique used in the transmitter is duplicated in the receiver to enable detection and decoding of the signal. Spread spectrum systems offer two important technological advantages over conventional transmission schemes. First, the spreading reduces the power density of the signal at the frequency within the transmitted bandwidth, thereby, reducing the probability of causing interference to other signals occupying the same spectrum. Second, the signal processing in spread spectrum systems tends to suppress undesired signals, thereby enabling such systems to tolerate strong interfering signals. This results in significantly higher signal to noise rations than can be achieved by conventional techniques such as AM that use no bandwidth spreading. The improvement in signal to noise ratio is termed processing gain. The two most common types of spread spectrum systems are direct sequence and frequency hopping. Direct sequence systems combine the information signal, which is usually digital, with a much faster stream of binary code. The combined information and code signal is then used to modulate an RF carrier. The binary code dominates the modulating function and is the direct cause of the wide spreading of the transmitted signal. The code is a fixed length pseudo random sequence of bits. The system continuously recycles the same binary code. Frequency *hopping* systems spread their energy by changing or hopping the center frequency of the transmission many times a second in accordance with a pseudo randomly generated list of channels. The same sequence of channels is used repeatedly, so that the transmitter continuously recycle the same series of channel shifts." 1

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1 Extract from FCC GEN. Docket No. 89-354, In the Matter of Amendment of Parts 2 and 15 of the Rules with regard to the operation of spread spectrum systems, Adopted June 14, 1990.