Minutes of the IEEE 802.4L Working Group

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Approval of the minutes of the New Orleans meeting. Under the heading Media violation, change: ...if one station can here a signal,... to: ...if one station can hear a signal... Under the heading Range, the improvement in range from 300 feet to 1000 feet by using error correction codes is now disputed. The minutes record what was stated, though what was stated may not be true.

MAC requirements submission: No preamble extension, no extended delimiters. The 802.4 MAC controller cannot support extension of the preamble between frames in a continuing message. This means that it is not possible to create the additional time needed for extending delimiters in a way that would be transparent to the MAC. This is unfortunate, since, if start and end delimiters are created by using additional channel (modulation) symbols, signal to noise ratio will suffer, unless the length of the delimiters is increased. As an alternative, more than 8 data bits could be sent per octet of MAC symbols, the additional bits could be used for error correction and/or for distinguishing data from delimiters. Tom has shown a way to use 5 bits to represent 4 data bits, or 9 bits to represent 8 data bits. Increasing the number of bits sent will increase bandwidth requirements or reduce MAC data rate. Sending additional bits allows the same modulation to be used for data and delimiters, simplifying modem design.

Test schedule. The work done by Rappaport on delay dispersion, and by Masleid on noise, make the test originally planned for Oshawa unnecessary. The Oshawa tests will be postponed so that new tests can been devised that will build on the information obtained thus far.

Range. The error correction code that might be used provides an improvement of 3 dB in signal to noise - assuming Gaussian noise. Attenuation is expected to be 10 dB per octave. This implies an increase in range of $2^{3/10}$ or 23%. This means that the range could be extend from 300 feet to 369 feet, not 1000 feet.

The range of this equipment is expected to be 300 feet. In an excellent environment, the same equipment may work at 1000 feet. Error correction codes will not extend the range by a significant amount if the noise is Gaussian.

Status of 802.4 Draft L. Draft L has been circulated in ISO as the second DIS for ballot. Voting terminates August 5, 1989.

Detected and undetected bit error rate. The receiver must provide an error rate better than 10^{-9}. If the receiver has some sense of signal quality, so that it can detect errors, it can provide a detected error rate ten times worse, that is 10^{-8}.

Error rate functional requirements. Bit error rate is the number used by modem designers. It does not represent the kind of errors that occur in high data rate systems. For the system, two kinds of error occur. Frames are lost (due to real or imagined errors), and frames are passed as valid that are in error. These are the sins of omission and the sins of commission. There should be numbers to describe frame loss rate and undetected frame error rate.

Noise Measurements: (Submission by Michael Masleid.) Measurements of the factory noise environment were made at Inland Steel using calibrated antenna as part of the MAP carrier band analysis in 1985. These measurements extended to 1 GHz. Peak values were recorded. To understand the results, it is necessary to understand the interaction of the test equipment with what is being measured.

Impulse and Gaussian noise measurement. Impulse noise measurements have to be corrected by 20 dB per decade bandwidth. Gaussian noise measurements have to be corrected by 10 dB per decade bandwidth. The measurements were done with 1 MHz bandwidth. At 6 MHz bandwidth, impulse noise values will be 15.7 dB higher, gaussian noise values will be 7.8 dB higher. Noise voltage is proportional to bandwidth for an impulse noise source. Noise power is proportional to bandwidth for a gaussian noise source. On the average, power is proportional to bandwidth. This does not apply to impulse noise. An impulse does not exist on the average. Errors are not caused by average power, they are caused by peak events. Impulse noise is very important in wide bandwidth systems.

Peak value of Gaussian Noise. To find impulse noise it is necessary to use a peak hold spectrum analyzer. Gaussian noise registers on a peak hold analyzer in a peculiar way: The longer a gaussian is observed, the more likely a large value will be observed. On a peak hold analyzer, Gaussian noise will cause the observed values to creep upward at an ever diminishing rate. If 1 GHz is observed as 1000 frequencies each with a 1 MHz bandwidth for 5 minutes, each 1 MHz span, or bucket is observed for 0.3 seconds, and is sampled (in a 1 MHz Nyquist sense) 600,000 times. If the largest value of 600,000 samples of a Gaussian is kept, the expected value will be 13.7 dB above the RMS value of the Gaussian. (The actual difference will be 15.7 dB, due to a 2 dB correction needed to account for filter noise bandwidth, detector, and logarithmic shaping characteristics of the analyzer.

Factory and residential noise. The factory is assumed to be more hostile than the retail or residential environment. The assumption should be checked. Motors in toys, vending machines, and appliances are not well shielded and create impulse noise at high frequency.

Range in the factory. Using the highest noise levels observed at Inland, and using the office attenuation values for signal propagation (and assuming no error correction), range may be only 40 meters. The work by Rappaport indicates that attenuation values in the factory are less than in the office, however.

Ping pong. The use of single frequency head end systems was abandoned at the last meeting. Single frequency head ends work by increasing the data rate and bandwidth by slightly more than twice, and using store and forward time division to get two channels. If the whole transmission must be stored, the delay is variable, and the protocol will not work. Single frequency head ends will work if frames are broken into short, fixed length segments, and the latency is added to the slot time. This is similar to the Cambridge Ring.

Leaky feeders. A leaky transmission line could be used as the radiator for a head end system. Good control and limiting of the radiation pattern can be achieved. It adapts well to narrow retail and controlled path AGV applications. It is more difficult to determine compliance with FCC power requirements when using leaky feeders.

Scramblers and differential coders. (Submission by Tom Phinney.) A message to be transmitted can be thought of as a polynomial. To randomize the message, it can be divided by a scrambler polynomial. The quotient is sent instead of the message. At the receiver, the quotient is multiplied by the scrambler polynomial. In the absence of errors, the product is the original message. A scrambler is normally an irreducible prime polynomial with only three terms $1 + x^{-m} + x^{-n}$ so that a single error in transmission expands to only three errors on reception. A differential coder works the same way, using a different polynomial.

Differential encoding and the FCS. If the scrambler or differential coder polynomial is relatively prime to the FCS polynomial, then the scrambler or coder will have virtually no effect on the error detectability of the FCS. The FCS is an irreducible prime polynomial and so the scrambling polynomials are safe. The only problem that can occur is if the scrambler still has the error in storage at the end of the frame due to an error near the end of the frame. There is no problem at all with differential encoding. Differential encoding will make errors in pairs, but the pairs do not fool the FCS. Frame loss and error rate is the important criteria, not bit error rate. The paired errors are not a problem. In fact, it is possible to find polynomials that cause a higher bit error rate, and actually improve performance at the frame level.

Summary of error protection capabilities of 16, 24, and 32 bit polynomials. (Submission by Tom Phinney.) An optimal 24 bit polynomial was found using 40 hours of time on a 5 Mips VAX.

4/5 rate codes for in band frame delimiters. (Submission by Tom Phinney.) A code which represents 4 data symbols with 5 symbols on the line is described. The code provides guaranteed timing transitions (as needed by FDDI). It is suitable for differential encoding (based on later analysis). It provides delimiters with Hamming distance 4. The 5 symbols provide 16 data quartets, start and end frame delimiters, preamble, and a quiet line transmitter off state. The code can be extended to 4/6 rate to provide DC balance. Clock recovery (from the data) and DC balance are not issues in 802.4L, other codes should be examined. An 8/9 rate code may exist that is suitable.

Use of codes for delimiters. Changing the modulation to indicate delimiters is actually a way of increasing the information rate in the channel. In a sense, 50% of the available rate in 802.4 carrier band is wasted on the odd chance that a delimiter might be sent next. If the channel modulation is chosen to provide the highest symbol rate possible, and a code similar to the 4/5 rate code is used to provide delimiters, better performance and greater simplicity might be achieved.

Scrambling for FCC requirements. The energy in the spread spectrum signal must be low at any discrete frequency to prevent interference with other services. A scrambler should be chosen that will cause this to happen when transmitting all ones or all zeroes. It may be necessary to have a strap on the modem to force the condition for FCC compliance testing. It is possible that the 11 bit chip code will accomplish this without a scrambler.

Rappaport. Work has been done at Purdue under NSF funding regarding the use of microwave spread spectrum communication to automatic guided vehicles. Noise and delay spread measurements have been made in a factory environment.

Single channel vs Dual channel. We have been talking about peer to peer networks and head end networks. In the language of the standard, this will cause confusion. A single channel system allows stations to talk to each other directly. (Single channel is what we have been calling peer to peer.) A dual channel system collects signals or symbols from stations, and distributes the signals or symbols back to the stations. Stations can not communicate directly. Dual channels can be arranged by time (Cambridge ring), frequency (broadband), or space (fiber optic dual cable).

Modulation. It is assumed that differential phase modulation is needed for mobile operation. Coherent phase modulation usually has better error rates, but requires an absolute sense of phase which may be difficult to maintain in a mobile multipath factory environment.

Bandwidth. A proposal was presented to allow co-located LANs, the available spectrum at 900 MHz would be divided into 3 FDM (frequency division multiplexed) channels. Using MSK type modulation at this data rate requires more than the available bandwidth. Therefore, the side lobes, and part of the main lobe of the MSK signal are filtered out. This causes some amplitude variation in the transmitted signal, requiring a linear final amplifier for the transmitter. The filtering is simplified because the linear phase requirements are relaxed, some interchip interference is permitted.

MSK. A model of the transmitter assumes a voltage controlled oscillator (VCO) driven so that phase is continuous, and frequency changes instantly: Frequency is stepped. The VCO operates at an intermediate frequency to make filtering practical. The result is mixed up to the proper frequency and amplified. Equivalent models exist.

Noise measurement with modulation. Gunther points out that noise measurements can be done by observing the effect of the noise on detection of a modulated carrier. Since an FM detector is nonlinear, the carrier must be modulated. Don proposes that the sine and cosine channels of a quadrature detector provide another way of making noise measurements.

Choice of demodulator determines the effect of noise. We can start with carrier to noise and after detection have energy per bit to noise power density. AM modulation has the same Eb/No before and after modulation. Using synchronous detection output is 3 dB better than input. Using FM the more bandwidth used, the better Eb/No after detection, however, at some Eb/No carrier to noise a catastrophic threshold is reached and detected Eb/No becomes zero.

Delay spread measurement. The two tone tests used by NCR assume things about the statistics of multipath that may not be valid. Exact behavior can be obtained using a network analyzer in frequency domain, converted to time domain using an FFT. Time domain measurement can also be done directly using radar techniques with gated CW or spreading code correlation.

Single channel system The single channel system requires point to point communication between all pairs of stations. All stations must be able to hear each other at all times. This limits the ultimate size of the network. The single channel system uses half the bandwidth or provides twice the data rate of the dual channel systems.

Dual channel frequency division multiplexing. The dual channel system requires that stations communicate to and from a central modem. The central (head end) system can have distributed receivers and transmitters, and so can support larger networks. Dual frequency allows the central modem to transmit continuously. With a continuous signal, the remotes can have long training times. The central site can reduce clock acquisition time (preamble) by transmitting timing to the remotes, which loop back the timing when transmitting to the central site. FDM requires twice the bandwidth of a single channel system.

Dual channel code division multiplexing. Chip codes can be used to supply multiple channels in the same bandwidth as a single channel system. Unfortunately, the cross correlation of short chip codes is too high. Dynamic range requirements make such a system impossible.

Dual channel time division multiplexing. Ping pong time division multiplexing requires slightly more than twice the bandwidth of a single channel system to provide turn around and acquisition time. The actual bandwidth used may be no more than required for FDM, since FDM requires a guard band between the transmit and receive frequency.

Modulation at 2 GHz. The same modulation that is used at 900 MHz can be used at 2 GHz. Since linear amplifiers are more expensive at 2 GHz, it may be necessary to use unfiltered MSC modulation. Channels at 2 GHz may requiring more bandwidth and wider guard bands.

Distributed head ends. If multiple antenna are used for the head end, they may be connected with a local area network. Transmitters could maintain a list of who can be reached. The receivers must have a way to arbitrate signal quality. A fixed time slot ring protocol can be used. The standard ring failure mechanisms must be dealt with. Since the ring need not be exposed, it can use a private protocol. Major time skew can be expected when the ring transmits unless some way is provided to synchronize the ring to the reference frame used by the remotes. A tree topology will not have the same problem with synchronization to the local reference frame.

The Section 10 .G interface probably can not be used between distributed receivers and their network. The .G interface does not provide a signal quality facility. The ring can do an online serial merge, then transmit the data service unit circulating on the ring. If the time since preamble is maintained, bit by bit replacement can be done within the frame. A forward error correction code can be used to support this facility. Error correction gives an indication of signal quality. Clean signal can be used in preference to corrected signal during the online serial merge. Additional information can be obtained from the correlation peak clock recovery.

There is no protocol that does what is needed within the distributed head end. What is needed is a distributed sort. We must choose among many receivers which one is best. Then take that information and distribute it to every transmitter. Using a ring architecture, the comparisons can be done at each receiver in the ring, so all comparisons can be done at once.

A tree or linear bus topology can also be used. If built using leaky feeders with a baseband return channel it may be made to appear simple to users. Each repeater in the feeder system contains a receiver for its feeder segment. It returns baseband signal quality and data service units up the feeder. The next receiver compares its signal quality with the baseband signal, and returns the better of the two up the feeder. Branches must choose between two baseband sources and the receiver at the branch node. The head end loop back point receives the best of the lot, and forwards that for distribution. The building block may be the same for ring and tree topologies. The forward channel in the tree topology may reduce transmission synchronization problems.

Delay spread can happen due to cable distribution to the distributed transmitters. Transmitters need a delay parameter to set the delay emitted before transmission. This can be used to minimize delay spread to the remotes. (This is not an issue when sending to the distributed receivers.) The value of the parameter may be more difficult to determine in a ring architecture, since it may have to vary depending on who is sourcing. It may be possible to fix this by requiring that the data service unit pass the start of the ring before transmission begins If nothing else works, graphite loaded sheets can be used to force attenuation.

Design considerations. There are many things still to be determined before this standard can be written. Exact values are not needed at this time. Look from a philosophical basis. Signal quality information is available. An absolute limit does not exist beyond which data is not worth trying to recover. An engineering judgement must be made. We are trying to engineer a reasonable system. We will rationalize or decisions after we make them. It is too early to make an assessment of the details of how this system is going to work, and whether we meet the underling requirements of 802. We need to get a system that very roughly seems to work, keep refining it, then see what needs to be adjusted. This is not a science, it is an art. How do you make something that is a compromise among companies, users, vendors, and market areas, and also fits under the banner of an existing standards agency? - And negotiate with mother nature about whether it can be done at all?

Ring chunk format. In a ring, someone must remove the message. Each chunk of message should have a start, signal quality indication, station address, data hunk, packet count, add to that another quality, address, and data hunk. This forms a train. If the quality at a station is not worse than the quality on the line, send the station information. Someone must originate a frame. (Presumably a synch pulse or token rotates in the absence of messages and allows only one originator. The synch pulse must be removed, and origination of the ring chunk must be delayed to allow other stations tine to lock onto the rf transmission.) Assume 12 stations arranged as a clock face. If ring station 12 was acquired the frame while holding the ring token, it is the originator of the frame. It originates all chunks, and will strip all chunks. If station 3 has better signal quality, stations 12, 1, and 2 must make due with what they have. Stations 3 to 11 can use the improved data from station 3. Station 12 removes the frame chunks. (If rf transmission is delayed until the chunk returns to the originating station, then all stations can transmit the same data with knowledge of the originating point. The originating station removes the frame chunk on the second pass. The second quality, address, and data segment fields could facilitate this, or a rotated twice flag could be used. The source can vary on a chunk by chunk basis.)

Two phase rings. Assessment. Repeating. A two phase ring would delay transmission of a chunk until a short assessment frame containing best quality and source address information circulates once without changing. Then the best address is used for sourcing and stripping.

Assessment lookahead. Frame chunk n should have the address and quality assessment for the data segment in frame chunk n+1. Arbitration is done one frame ahead of transmission as in the two phase ring, but the structure is simplified. Frame chunk size should correlate with the forward error correction size. If the data segment is 100 bits, and the assessment and ring address use 60 bits, the data rate on the ring can be less than twice the data rate of the system. Since a MAC frame can be built from individually selected chunks, velocity and fading problems are less important.

MSDU loss rate. If the detected bit error rate is 10^{-8}, then for a 222 byte frame, the frame loss rate will be 1 per 56,310 MSDU's, or 10^{-8} MSDU lost per bit.

MSDU undetected error rate. The number of MAC service data units, (MSDU), reported with undetected errors (eg. passes CRC, modem signal checks, FEC checks.), per unit time. The 802 functional requirement is less than one undetected frame error per year. This assumes a 200 byte data service unit to the network layer, a 222 byte frame, 5 Mbit/second, zero protocol overhead, and 100 % frame utilization of the bandwidth. This is approximately 10^{+11} MSDU's per year. Therefore, MSDU undetected error rate is approximately 10^{-11} per year, 10^{-11} per MSDU, and 5.6×10^{-15} per bit.

The frame error rate functional requirement and bit error rate requirements are independent, and predate the 32 bit FCS. The frame error rate will be met assuming the 32 bit FCS, random 10^{-9} bit error rate, and Hamming distance 4 end delimiters. The frame error rate might be met with less protection, but that would not meet other 802 requirements. The FCS protects from burst errors of length less then 32. Single bit errors must not create unbounded error bursts. Hamming distance 4 helps with that.

Noise bursts length. Time domain measurements at Inland show 20 MHz bursts decaying in 3 to perhaps 100 cycles. The burst length varies from .15 to 5 microseconds. Measurements done by RCA indicate 2 to 4 microsecond duration.

Hamming distance 4 end delimiters. If end delimiters have a Hamming distance of 4, then up to 3 errors can be tolerated. Data can be turned into an end delimiter with 4 errors. When a false end delimiter is created, the data preceding it becomes a false CRC. Assuming data is random (not a good assumption) the probability that an undetected frame error will be created is 2^{-32} or 2.3×10^{-10}. The MAC can generate as little as one octet of preamble between start and end delimiters at 1 Mbit/second. This does not allow a lot of time for the physical layer to improve the quality of the delimiter. A no vote at ISO DIS might make the interframe preamble length programmable.

Making robust delimiters. End delimiters can be made robust by increasing time, signal, or data space. Increasing time (given MAC design) must come from increasing preamble. Increasing code points reduces signal to noise ratio, increasing data space with 4/5 or 8/9 rate codes reduces data rate.

4/5 (8/10) rate codes. The end delimiter is a 10 bit pattern that has a Hamming distance of 4 from the 256 code words that represent data. Data has 2 or 3 bits set per 5 bit code word, Delimiters have 0 or 5 bits set per 5 bit code word. A delimiter 5 bit code word differs from data by at least 2 bits. Therefore, the end delimiter octet has distance 4 from all data octets. Also, Hamming distance of the data is maintained. Unfortunately, in the FDDI 4/5 rate code, a one bit error in the code can change data 0 to data F, reducing the Hamming distance to one (or two, since the F is a burst error). The 8/10 code can be sent in dibits suitable for QPSK signalling. Assuming impulse noise, the chip code itself may need to be interleaved, or distributed over time, or changed into something else, which gets into heavy duty coding and information theory. Perhaps the chip code should be thought of as a 44, 66 or 88 bit code, rather than an 11 chip x 4, 6, or 8 code. (Ed: since the chip code is applied to dibits, this may all be confused. Perhaps the code is 22 bits, or the octets are 44 chips, and the delimiters are 33 chips.)

Co-located LANs versus One LAN. The higher bandwidth needed for the 8/10 code makes it difficult to support 3 channels. A single channel using the whole bandwidth will support the same or more total traffic. Co-located LANs on a single channel will not be stable, however, since most traffic is token passing, tokens will tend to be hit. If Co-located LANs are tied together into one large LAN it is not a problem. The management of a shopping mall, or the LAN manager of a factory could arbitrate usage. Though this may be unpalatable to individual retailers, their data is no more private with 3 LANs than it is with one LAN. Privacy is obtained by encryption at a higher layer.

66 bit chip codes. It may be possible to find a 66 bit chip code for the delimiters that has a large distance (small cross correlation) to all possible patterns of 6 x 11 chip codes. (Ed: or is that 33 bit chip codes to 3 x 11 bit chip codes?) The additional correlator can be expensive in silicon, but there may be ways to pipeline the architecture silicon.

Dual correlators in Broadband. In broadband, the data stream comes from a 50% slicer on the eye pattern. Non data is signalled using half high pulses. It is easy to generate a two wide half high pulse in broadband because of the modulation used. A second stream uses two additional slicers, at 25% and 78%, this stream goes to a delimiter pattern correlator. If the delimiter pattern correlator finds a delimiter, the delimiter stream is substituted for the data stream. A three level code would have cost at least 6 dB signal to noise ratio. Using this method, only 1 dB was lost. Rather than 3^8 code bits sent, it is more nearly 2^8 plus 5.

Code interleaving. 4 dibits are sent per octet. 11 chips for dibit 0, then 11 for dibit 1, then 11 for dibit 2, then 11 for dibit 3. Interleave can be used, sending one chip from dibit 0, one chip from dibit 1, one chip from dibit 2, one chip from dibit 3, then the next chip from dibit 0, the next chip from dibit 1, and so on. Rather than sending:

$C_{a0}C_{b0}C_{c0}C_{d0}C_{e0}C_{f0}C_{g0}C_{h0}C_{i0}C_{j0}C_{k0}C_{a1}C_{b1}C_{c1}C_{d1}C_{e1}C_{f1}C_{g1}C_{h1}C_{i1}C_{j1}C_{k1}$
$C_{a2}C_{b2}C_{c2}C_{d2}C_{e2}C_{f2}C_{g2}C_{h2}C_{i2}C_{j2}C_{k2}C_{a3}C_{b3}C_{c3}C_{d3}C_{e3}C_{f3}C_{g3}C_{h3}C_{i3}C_{j3}C_{k3}$

Send:

$C_{a0}C_{a1}C_{a2}C_{a3}C_{b0}C_{b1}C_{b2}C_{b3}C_{c0}C_{c1}C_{c2}C_{c3}C_{d0}C_{d1}C_{d2}C_{d3}C_{e0}C_{e1}C_{e2}C_{e3}C_{f0}C_{f1}$
$C_{f2}C_{f3}C_{g0}C_{g1}C_{g2}C_{g3}C_{h0}C_{h1}C_{h2}C_{h3}C_{i0}C_{i1}C_{i2}C_{i3}C_{j0}C_{j1}C_{j2}C_{j3}C_{k0}C_{k1}C_{k2}C_{k3}$

This provides some protection from impulse noise by taking some of the noise energy against each dibit, rather than all against one.

Review of token passing and recovery algorithm. Don't lose tokens. Don't create more than one. It is expensive. It may be appropriate to have a station that knows that it is in trouble remove itself, or at least go to immediate response mode only.

Polled networks. If the distributed ring is the only token holder, and it polls by immediate response, token loss can be avoided. Ordering of LLC message is not well supported in immediate response. LLC type one can not duplicate or deliver messages out of sequence. Field bus passes control of the token from the master for a delegated time. Token loss can be avoided that way also. A station that does not have a token, and is not polled, can never talk.

Fades geometry. Fades are expected at half wavelength intervals away from flat metal surfaces. Within the coherence interval of a 6 MHz channel at 905 MHz, about 45 wavelengths, there will be deep fades near the wall. If there are many reflecting surfaces, not just one flat one, this is not a problem. Other paths will replace the direct one.

Delay versus load for token passing. For token bus, the delay versus load is 1/(1-x). If at zero percent load it takes 10 ms for the token to go around, then at 50 % load it will take 20 ms, at 75% load it will take 40 ms, at 87.5 % it will take 80 ms. At light loads, many more tokens are sent than data frames. If a message is 4 times longer than a token, the network must be at 80% loading to make the number of tokens sent equal to the number of data frames sent.

Processing gain using 4/5 rate code. If a 9 bit code is used instead of an 11 bit code, the processing gain will be 45/4, which may meet FCC requirements. It will not be acceptable under current FFC interpretation. (Ed: Unfortunately, no 9 bit code exists. The next shortest Barker sequences is length 7, the next longest is 13.)

44 chip codes as 8/44 rate codes. One octet uses 256 possible sequences of 44 chips. Potentially there are 2^{44} or 1.7×10^{13} sequences of 44 chips. It is reasonable to assume that 4 additional sequences can be found for 44 chips. (An 8.0224/44 rate code is better than an 8/55 (4/5 x 2/11) rate code).

MSK modulation. MSK transmits f high, or f low. One half dibit of fH or fL will change phase by +90 degrees, or -90 degrees. In two bit times, phase can change 0, +180, or -180 degrees. The phase diagram must be sampled twice to tell if 0 degrees represents fHfL or fLfH. The phase time diagram looks like a trellis of triangles, or a modulo cylinder with spiral tracks. (QPSK allows 4 phases per sample time, not just two. Diagonal paths can be followed in the phasor diagram. More frequencies than fH fL are needed.) At any one time MSK can only be at 1 of 2 phases, not 1 of 4 phases.

Noise measurement data presentation. Measurements were made at Inland Steel that indicate the presence of significant impulse noise up to the 1 GHz limit of the test equipment, and probably well beyond. The data presented is corrected for antenna calibration. Care must be taken when reading the graphs. Instrument noise floor traces the calibration factor of the antenna, it does not represent structure in the noise floor of the environment. Peak hold measurements show wide band impulse noise as discrete lines above the instrument base line. Impulse noise lasts for microseconds. The spectrum analyzer sweeps each 1 MHz bucket in 1 millisecond when using a 1 second, 1 GHz sweep. The impulse is observed at whatever frequency the analyzer happens to be at when the impulse occurs. If a given impulse event happens often enough, the analyzer will eventually map out the complete spectral density of the impulse.

Making better noise measurements. More must be learned about noise at 1 GHz to determine what can be done about it. Time domain measurements are needed. Direct measurement is not practical. A quadrature demodulator can translate the noise events to base band. The I and Q components can be sampled and stored. The stored values can be used to reconstruct the actual event. Since a quadrature demodulator is most likely for the modulation used by 802.4L, the stored values may be directly useful. (If an FM demodulator will ultimately be used, it may be useful to measure noise with that. The I and Q measurement is linear however, and can be used to reconstruct the actual noise event. Once a computer model of the actual event is created, FM demodulation schemes can be tested in simulation.)

More on Rappaport. There is more information available from Rappaport. He has begun to analyze use of a central hub. His work is parallel to our own. He is examining multiple antenna spacing in the factory environment. He observes 100 ns delay spreads within 10 meters of an antenna, indicating that factories are giant echo chambers.

Achieving high data rates in spite of large delay spreads. The literature suggest that a data rate of 250 kbit/s may be difficult to achieve. Delay spread causes intersymbol interference. To reduce intersymbol interference move the symbols further apart in time. This is done by using 4 phase modulation, which doubles the time between symbols. Using spread spectrum concentrates the symbol into a correlation peak, further reducing intersymbol interference. To move the symbols still farther apart use multiple chip codes, perhaps 4 of them, so that each of the 4 correlators quadruples the time between symbols. Code division multiplexing works in this case because all codes originate at the same power level by default. If we disperse a symbol over a huge time, then transmit it over a dispersive channel, channel dispersion is not as important.

Measurements that are still needed: Measurements that have been made indicate further testing is needed. More needs to be learned about noise in the factory and retail environment. More needs to be learned about delay spread in a multi antenna distribution system.

Impulse Noise Measurements. Noise has been assumed to be Gaussian, 18 dB above thermal, not impulsive, at 900 MHz. This may not be correct. Time domain measurements are needed to find the interaction between the expected impulse noise and the demodulation scheme. Duration and repetition rate must be determined. Measurement needs to be done at factory and retail locations. The simple peak hold measurement could be done in retail locations to determine if more sophisticated tests are needed there. (Use of FEC to ride through impulse noise still needs to be examined. It is better to ride through rather than depend on power to ride over noise.)

A suitable test device could be built using a preamp to drive off-the-shelf mixers. A local oscillator and 1/4 wave delay line can turn the mixers into a quadrature detector. A fast digital sampling scope can record the I and Q channels from the mixers. A counter can record the number of events.

Multiple antenna delay spread measurements. Chip spreading radar, inverse FFT network analyzer measurement, or pulse radar can be used to obtain the impulse response of the channel with one antenna and one receiver. The multiple antenna network can be determined from superposition of many measurements, in which the transmitter antenna is moved to each of the distribution system sights, and the receive antenna is held stationary. The impulse response from each of the distribution sights can be combined with variable delay to simulate behavior of a cable driven distribution system. (Not to be confused with changing the position of the receiver.) The measurements should be done for as many receiver sights as practical

Reducing delay spread in factories. Bell labs did simulation of QPSK, not using spread spectrum. They achieved a 1 Mbit rate. If you have flat Raleigh fading, as you increase the data rate the outage goes up because you have less energy per bit, a fixed SNR. If 100 ns delay in an indoor environment is added, it is still possible to reach 1 Mbit/s without spreading. With spreading, indoor environments should be no problem. When the delay spread reaches 500 ns, as it may in a factory with widely spaced antenna, the engineering may be more critical. If antenna are spaced 25 meters apart, the factory delay spread might be reduced to 100 ns everywhere. Then the factory may work as well as the office. The array of antenna for a GM plant may be a 10 by 20 grid. The 16 next closest neighbors in such an array will be 1 symbol time delayed. The power from the those signals may exceed the power received from the nearest source. In such a case, it may be necessary to place microwave absorbers in strategic locations.

An alternative for Non Data symbols. It may be possible to generate non data symbols by holding position in the I Q plane for one bit time. Normally successive samples alternate between I and Q. By holding one, successive samples will be at Q and I. Twin decode paths can again be used, looking for data in the I and Q channel, and delimiters in the Q and I channel. Since the correlation paths are the same, a pipeline structure can be used to minimize hardware.

I would like to thank Tom Phinney for recording the following minutes for the Wednesday meeting:

Band selection. Bruce Tuch discussed the rationale for choice of bands. The FCC has three bands available for this type of use. The lowest and first choice, 902-928 MHz, is just above TV-UHF. The new European cellular radio is at 915 MHz, so many low cost components are available for this band.

To provide multiple channels for co-located LANs (e.g. office buildings, or shopping malls), the 900 MHz band needs to be divided into at least three channels. To minimize the bandwidth, MSK-like shaping of the baseband signal is employed.

Receiver threshold:	-80 dBm
Transmit power:	+20 dBm
Adjacent channel rejection:	60 dB
Hard limiting:	40 dB
AGC range:	60 dB (time is provided in preamble length)
3 dB bandwidth:	6.2 MHz
60dB:3dB bandwidth ratio:	1.6

The FCC requires out-of-band signal to be at least 20dB down. Actual channel skirts cross the band edge 30 dB down. Three channels are wanted in 902-928 MHz; two channels are required for a dual-channel head ended multi-antenna distribution system.

Power measurements. Don Johnson started a discussion of how to address FCC power measurements of a distributed antenna, since the rulings to date assume a single-point source. Michael Masleid observed that if a measurement were made from a distance such that the angle subtended by the building wall is such that sin(x)/x 1, then the measurements will approximate that from a point source. At nearer distances the measurement must be considered as power per subtended angle.

Discussion of the effect of coherence within and among the radiators led to a realization that there should be no intentional coherence among radiators. However "leaky radiators" were self-coherent, and fired in a conical pattern.

A long discussion of the quasi-peak measurement technique led to the realization that 16 point sources would eventually sum voltages so that they would look like a single point source of 24 time the power, and that some type of time-integration or low-pass filtering would be needed to save us. (In fact, such a multi-antenna system looks like a phased array with random beam-forming.)

Modulation. The modulation to investigate first is DOQPSK with greater than Nyquist filtering of the baseband signal. (DOQPSK = Differential Offset Quadrature Phase Shift Keying.)

The 11 - chip spreading code is + - + + - + + + - - - (phase rotations).

A network ID seems essential to provide

a) ability to contract the dynamic range of small systems

b) ability to limit the effect of interference from other systems by reporting their reception as bad_signal.

Forward Error Correction:

1) Intrinsic Redundancy of DOQPSK to combat isolated errors.

2) Multi-symbol interleaving of chips to combat impulse noise.

3) Extra redundancy in the form of an additional FEC precoding. This alternative is much to be avoided.

Scrambler:

$1 + x^{-4} + x^{-7}$ $(1 + x^{-3} + x^{-7})$

$1 + x^{-6} + x^{-7}$ $(1 + x^{-1} + x^{-7})$

Encoding of PHY symbols:

0 & 1 from MSK-like DOQPSK

Delimiters from intentional code violations (multiple errors) from emitting a single phase change, and later another single phase change within the same octet.

Next Intermediate Meeting. Due to a clash of our September Intermediate meeting with a meeting of the Field Bus committee, it was decided to change our meeting dates.

The new dates are September 11-15, 1989. Start will be on Monday September 11, 13.00 h. Closure will be on Friday September 15. noon. The meeting will be organised by Orest Storoshchuk in downtown Toronto.