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TITLE: **ASSUMPTIONS THAT LIMIT VALIDITY IN MODELING LISTEN-BEFORE-SEND ACCESS METHODS**

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BACKGROUND

In modeling and simulating autonomous systems (no infrastructure), it is assumed that the Station can determine that the channel is available by listening and determining from what is heard that there is a good probability that the transmission will be successful and will not interfere with another in progress. Early, incompletely refined simulation models show no instability for high loads and throughputs of the order of 50% of channel capacity.

It is now asserted that this conclusion about throughput may be true for the assumptions made, but may not be generalized to describe the performance of large scale systems. The considerations involved are now described.

CONCLUSIONS

For a listen-before-talk, autonomous non-infrastructure model to be valid, the following requirements must be considered:

1) The fading, and consequently the required margin, must be explicit on the diversity means or other justification if exception is taken to the use of Rayleigh fading.

2) For an analyzed cluster of Stations, there must be 6 to 8 like-type contiguous clusters all with the possibility of simultaneous use.

3) A large enough number of Stations must be used so that congestion takes place in the medium rather than in an orderly queue behind a buffer in the Station.

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In modeling and simulating autonomous systems (no infrastructure), it is assumed that the Station can determine that the channel is available by listening and determining from what is heard that there is a good probability that the transmission will be successful and will not interfere with another in progress. Early, incompletely refined simulation models show no instability for high loads and throughputs of the order of 50% of channel capacity.

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Confidence in the models presented has been reinforced by some experiments with results that are consistent. A sufficient experiment would be costly and complicated to actually produce the traffic levels and position distributions that may occur in large scale systems.

The radio assumptions made are reasonable, if not accurate, for individual paths and for assuring sufficient signal level for successful communication. They are deficient in the assumptions about the effect and level of interference from large numbers of Stations surrounding the analyzed cluster.

It is necessary for valid models to recognize the inherent conditions of "interference-limited" radio system design without which there is no possibility of achieving sufficient spectrum utilization.

Some observations about this type of system are presented including the particular implications on model design.

Because of the need for high spectrum utilization concurrently with wide bandwidth, these factors may be decisive in choosing radio modulation and access methods.

RADIO SYSTEM PARAMETERS

The available frequency space, the time dispersion of the radio paths in the working environment, the need for 100% area coverage in the target area, the target success probability for one packet transfer, the limits on worst case access delay, and many other factors go into the determination of the amount of communication that one bandwidth allocation can carry.

The units of measure should be as ETSI RES-10 described:

N megabits/second per hectare for a given allocation of spectrum bandwidth.

BANDWIDTH ALLOCATION

It is true that the upper ISM bands are 83 and 130 MHz wide, but it is <u>not true</u> that either of these bands should be divided into a number of channels sufficient to resolve overlap and provide 100% area coverage at the same time.

The leading PCN (pocket telephone proposals) are asking for a 40 MHz allocation in the "emerging technologies" band near 2 GHz, and it will be very difficult for LAN to get any more.

The minimum usable LAN bandwidth is primarily determined by path length resolution with spread spectrum modulation and also by minimum usable data rate.

Bandwidth : Bit-rate Ratio

If the chipping rate must be 5 to 8 times data transfer rate, then a 40 MHz band allocation is unlikely to provide more than 6 Mbits/s of peak transfer rate. There are two alternatives:

1) Accept the data rate that is obviously possible, or
2) Discover and apply more technology to improve the ratio.

It is this Contributor's belief that better than 4:1 is possible, but this would just reach 10 Mbits/s in new frequency space but might reach 16 Mbits/s in the ISM bands.

Chipping Rate Consideration

When spread spectrum is used two path lengths differing in arrival time by one chip are independently measurable. Smaller differences increase the degree of Rayleigh fading by the vector addition of the signals in one chip interval.

At a 25 Mc/s chipping-rate, the period of one chip is 40 nanosec. In this time, the propagation distance is 12 meters.

This resolution will not do much to reduce the fading from floor bounce, but it will help on reflections from far walls and furniture off of the direct path.

On this criteria, it is apparent that a chipping-rate twice as high would be helpful, and that half as high would be significantly degrading.

The chipping-rate consideration is independent (first order only) of the degree of symbol coding or the type of modulation. Deriving channels by code-division at the described chipping-rate would be a possibility, but not frequency-division channelization with narrower SS channels.

If channels are derived from a 31-bit symbol, as suggested by J. Cheah (91-7), 12 channels of 1 Mbits/s each could be obtained from a chipping rate of 31 Mbits/s occupying a 40 MHz band--provided that any or all of them could be used simultaneously. If the codes are used to separate overlapping coverages where the discrimination is not stressed, a lesser but useful result is obtained.

C. Rypinski (91-96) used this code property to isolate overlap in coverage between Access-points stations. There is then at most 12 Mbits/s of aggregate capacity spread across many coverages. The peak capacity of one coverage remains 1 Mbit/s regardless of unused capacity in nearby cells.

The dynamic range and internal signal-to-noise ratios might not allow simultaneous use of all Access-points for near 100% of the requested communication.

FREQUENCY REUSE CONSIDERATIONS

A one-channel model in which it is infrequent for two successful communications to occur simultaneously is invalid for large scale. To show the effect on one cluster, it must be surrounded by six others. <u>Seven simultaneous non-interfering</u> communications must be commonplace. The isolation of each system must not be assisted by obstacles which are not consistently available in the environments for which a service capability is specified.

With full frequency reuse in a plan where there is continuous unbroken coverage, it is inevitable that at full load the aggregate capacity of one cluster be diminished to a small fraction of what it would be without the surrounding systems. If this is not true, the simultaneously used transmitters have not been put as close together as they might be.

Crowding of simultaneously used transmitters on a shared frequency is inherently necessary to obtain the most capacity from a given system bandwidth.

Interference Limiting

To the first order, the geometric pattern of simultaneously usable links is constant, and may be scaled up or down as long as the distance function of propagation is consistent. Up or down scaling must be done in such a way that there is continuous area coverage.

It is well known that obstructed propagation attenuates about 11 dB/octave of distance with large departures from average in specific cases. With omni-directional antennas and infrastructure-based service, it would require 7 to 16 frequency sets to get continuous area coverage at this attenuation constant.

In planar free space with an attenuation rate of 6 dB/octave, it might take 49 or more channels in a regular pattern for each to operate simultaneously and non-interfering.

The smaller the coverage area defined, the more probable it is that unobstructed paths will be available.

Simultaneous use of one frequency is more difficult with smaller coverage area because interference increases non-linearly.

For this type of assumption, the limit on communication is not transmitter power or receiver sensitivity, assumed the same for all, but the signal-to-interference ratio where the interference is the composite energy of all nearby cochannel uses.

Minimization of fading and the necessary margins are the main methods of optimizing for this type of performance. This is the factor which causes a robust binary modulation to be more spectrum efficient than a multi-level modulation using less bandwidth.

If, in the model, there is no summing of the energy of the nearest six stations operating on the same channel at the same time, then it does not cover the case of maximized capacity for a given spectrum allocation.

Fade Margin Considerations

It has been widely believed in past years that more signal is always better. Additional transmit power reduces the instances of fading below a usable level. The fading that comes from interposed obstacles is intuitively understandable, but the fading from vector addition of multiple signals from different indirect paths is more complex. The vector addition is characterized by the Rayleigh distribution, which is not symmetrical as is the normal distribution.

On a Rayleigh distribution, it is almost impossible to get above a specified minimum level more than 90-95% of the time. On the upside, only a small increase is probable, but the downside may be sizable.

A factor of 6-12 dB or more of margin goes into most radio path calculations to reduce the probability of outage. It is therefore worthwhile to incorporate anti-fading provisions in system designs.

Applicability of Diversity to Portable Stations

It is not impossible but quite difficult to visualize an acceptable diversity arrangement for portable computers working peer-to-peer. This point is important because without diversity the assumption of normal distribution fading is not allowable. With Rayleigh fading, much more fade margin is required, and yet only yields an improvement--not a solution.

Implementing Diversity

A minimum of two antennae must be used. If they are of like vertical polarization, they must be spaced some distance to provide space diversity. In the alternative, one might be horizontal and the other vertically polarized provided that the horizontal is omni-directional (possible but not obvious).

With two or more suitable antennae, they may be combined by switch selection of the best one with the selection lasting the duration of a burst transmission, or they may be linearly combined with a more elaborate receiver design.

These techniques would be readily feasible at an Access-point but much less so at a portable Station.

TRAFFIC LOAD GENERATION

If all the traffic were generated by one Station, the serialization of the channel would take place within the Station rather than in accessing the radio channel. A sufficient number of Stations must be used so that there is no queuing within one Station, otherwise the potential for collisions on the channel is under-represented.

CONCLUSIONS

For a listen-before-talk, autonomous non-infrastructure model to be valid, the following requirements must be considered:

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