Techniques to Achieve Dense Deployment in Broadband Wireless Network

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Abstract - For wireless broadband systems to succeed as a major communication solution in the 21st century, they must be the primary communication solution in the bandwidth range of 100 Mb/s and higher. This bandwidth range is not effectively served by copper or fiber optic networks. Key technical characteristics of a primary communication network are that it be reliable, maintainable, generally accessible, easy to deploy, cost effective, etc. This paper addresses a solution for dense deployment, which is related to the key issue of accessibility. Common questions in wireless networks are "can the customer be reached?" and "will the performance be adequate?" Technical issues are system gain versus distance and interference control for dense deployment. This paper provides in-depth analysis of interference control by studying the impact of antenna patterns, different transmit power control schemes, frequency assignment and polarization. In conclusion, consecutive point networks should be able to provide broadband communication service to any medium to large buildings in any city.

1. INTRODUCTION

Bandwidth demand of Internet users continues to grow exponentially. There are three transmission media that are currently used, namely copper, wireless and fiber. In copper media, the access speed is enhanced from 56Kb/s to 1 –10 Mb/s by introduction of digital subscriber line (DSL) and cable modems. The key importance of these technologies is leverage of deployments based on existing imbedded copper wires or coaxial cables to deliver higher bandwidth. Fiber, on the other hand, could provide all the bandwidth required by users, but the economics limit wide spread accessibility in a metropolitan area. In terms of wireless access, very low data rates are being or will be addressed by mobile technology. The unlicensed frequency band at 2 - 5 GHz addresses local access of up to 5 Mb/s. The licensed bands at 20 to 40 GHz have an opportunity to be the primary access communication system for 10 to 1,000 Mb/s.

The fundamental requirements for a primary communication system are cost effective wide access availability, network and service reliability, performance, etc. In wireless terms, the wide access availability, network reliability and performance are related to mutual interference among radios, usually considered "black magic". This paper addresses the methods of mutual interference control for one broadband wireless access network solution, Consecutive Point Architecture [1], that has the potential to be the primary network access.

2. LINK BUDGET

For simplicity, the link budget analysis is based on a two unidirectional link configuration as shown in Fig.1. The direction of transmission of the two links is N1 to N2 and N4 to N3. Identical radios are used in these two links. The link budgets for the signal paths in dBm are:

$$R_2 = T_1 - L_{12} + G_{12} + G_{21} \geq R_t \tag{1a}$$

and

$$R_3 = T_4 - L_{43} + G_{43} + G_{34} \geq R_t \tag{1b}$$

The expressions for signal to interference ratio (C/I) in dB are:

$$R_2 - I_{42} = R_2 - R_3 - L_{43,42} + G_{43,42} + G_{21,24} + L_{p42} + L_{f42} \geq (C/I)_t \tag{2a}$$

and

$$R_3 - I_{13} = R_3 - R_2 - L_{12,13} + G_{12,13} + G_{21,31} + L_{p13} + L_{f13} \geq (C/I)_t \tag{2b}$$

assuming $G_{12} = G_{21} = G_{43} = G_{34}$,
where
R_x is the received signal level of receiver x in dBm
R_t is the received signal threshold for desired performance in dBm
T_x is the transmit signal level of transmitter x in dBm
I_{xy} is the interference level from transmitter x to receiver y in dBm
L_{xy} is the path loss between x and y in dB

$L_{ab,cd}$ is the relative path loss between link ab and cd in dB
L_{fxy} is the frequency discrimination from transmitter x to receiver y in dB
L_{pxy} is the polarization discrimination from transmitter x to receiver y in dB
G_{xy} is the antenna gain in the direction of x to y in dB
$G_{ab,cd}$ is the relative antenna gain in the direction of a to b and c to d in dB
$(C/I)_t$ is the received signal level to interference level ratio threshold in the link budget allocation in dB

(1a) and (1b) are the necessary requirements for the signal to reach the receiver at a sufficient level for acceptable performance. (2a) and (2b) are the necessary requirements for an interference level that allows for acceptable performance. The C/I equations are more complex due to more path and deployment variables, like $L_{ab,cd}$, L_{fab} and L_{pab}.

3. ANTENNA PERFORMANCE BENEFIT

Antenna performance can be divided into three parts: main beam, sidelobe and polarization discrimination. Antenna gain in the main beam impacts (1a) and (1b), and sidelobe and polarization discrimination impacts (2a) and (2b). The most difficult and important question to answer is what is the quantitative benefit from one antenna to another. To date high performance antennas (HPA) have been the most cost effective and versatile solution for controlling interference in a radio network. In general antenna discrimination analysis the radio link relationship can be divided into three categories as shown in Table 1:

a) main beam of an antenna pointing to main beam of another antenna, other than the intended antenna;
b) main beam of an antenna pointing to the sidelobes of another antenna; or
c) sidelobes of a antenna pointing to sidelobes of another antenna.

In terms of radio link deployment planning, one definitely should avoid (a) and minimize (b). In other words, radio network co-existence should be based on the antenna discrimination from sidelobe to sidelobe.

For quantitative analysis, this section introduces two methods of evaluating the benefit from an antenna pattern. One method is to evaluate the antenna discrimination in terms of the relative angle between two links. To illustrate this method, two antenna patterns are assumed in Table 2. One antenna pattern is compliant with FCC Part 101.115 category A [2] and the other has better antenna sidelobe performance in the first 30 degrees off the main beam. Table 3 shows the β/ϕ angle requirements for achieving a certain antenna discrimination, where β and ϕ are defined in Fig.1. The high performance antenna achieves a higher antenna discrimination than the FCC compliant antenna.

The second analysis determines the probability of achieving a certain level of antenna discrimination with random antenna placement in a radio network. The analysis assumes independent β and ϕ variables with a uniform distribution over 0 to 360 degrees. Table 4 shows the cumulative antenna discrimination, i.e. the probability of exceeding 50 dB of antenna discrimination is 0.969 for the FCC compliant antenna or 0.985 for the high performance antenna pattern. For example, if 50 dB antenna discrimination is used in the initial radio planning, then one has 3.1% or 1.5 % of the links requiring rework based on the FCC compliant or the high performance antenna respectively. The real benefit is either simplified radio deployment or greater density deployments.

4. TRANSMIT POWER CONTROL

The second most important terms in (2), after antenna discrimination, are the $(R_2\text{-}R_3) - L_{43,42}$ and $(R_3\text{-}R_2) - L_{12,13}$. The optimum condition for maximum C/I, while other terms remain constant, is when

$$\begin{aligned}(R_2 - R_3) - L_{43,42} &= (R_3 - R_2) - L_{12,13} \\ &= 0.5\,(L_{43,42} + L_{12,13}) \qquad (3)\end{aligned}$$

Since L_{43}, L_{42}, L_{12} and L_{13} are time variant [3], then the optimum receive signal levels must also be varied with time. This requirement is not practical to implement, because the radio network commonly has multiple interfering sources and a real time computation of every pathloss is impossible. More importantly, (3) indicates that the relative receive signal level does impact overall radio network coexistence in dense radio deployments.

An alternative practical solution is to minimize the interference level from each link under all conditions. This solution might not be optimum, but it can be performed in practice. The interference equations for a two radio link configuration are

$$I_2 = T_4 - L_{42} + G_{42} + G_{24} - L_{p42} - L_{f\,42} \qquad (4a)$$

$$I_3 = T_1 - L_{13} + G_{13} + G_{31} - L_{p13} - L_{f\,13} \qquad (4b)$$

(4a) and (4b) indicate that interference is reduced, if T_4 and T_1 are at a minimum all the time.

This section details three different transmit power control schemes. The simplest one is the constant transmit power control scheme defined as setting the transmit power to the minimum level required to maintain the desired radio link performance under the worst conditions, i.e. maximum pathloss and interference. Once the transmit power is set, it will remain constant under all circumstances.

The second scheme, commonly known as automatic transmit power control, (ATPC) [4] maintains the received signal constant. The transmit power is continuously changed to maintain the received signal at a pre-set value. This pre-set received value is set manually.

The third scheme, adaptive transmit power control (A_dTPC) [5]-[6], continuously adjusts the transmit and received power levels to maintain the desired radio link performance, i.e. maintain a desired bit error rate in a digital communication system.

Fig. 2 consists of three constant receive power level contour plots for the purpose of illustrating the interference of the three schemes mentioned above. The contour drawn in bold line represents a contour that has a receive level of R_t under a maximum pathloss condition. The intended receiver will be at the edge of the main beam contour if there is no interference. Under interference conditions, the receiver location will be inside of the R_t contour, but the exact location is based on the amount of interference that the receiver has to overcome. The R_t contour allows fixing the transmit power for discussion purposes. Also the maximum distance point of the R_t contour assumes half a mile long and that the transmitter is located in a rain region that requires 40 dB of rain margin.

Plot 1 shows the R_t contour together with a clear-day R_t contour plot that is computed with the same transmit power on a clear day. This set of contours represents the constant transmit power control scheme. The maximum distance of the clear-day R_t contour is 12.5 miles. This increase in clear-day distance will introduce many more interfering links that would not be there under a heavy rain condition. If the signal to interference level ratio is lower than the desired requirement, then the transmit power has to increase again. Unfortunately, increasing the transmit power is not always the right solution. One might have to change polarization and frequency as discussed in section 5. In terms of optimization, this scheme does not provide minimum interference all the time.

Plot 2 shows a set of R_t contours to overcome 10dB interference level. As stated earlier, moving the receiver location is the solution for heavy rain. So the R_t contours remains the same. On a clear day, the solution for overcoming 10 dB of interference is increasing the transmit power. So the contour on a clear day has a larger foot print. Plot 2 meets the minimum transmit power requirement, only if the interference is constant at 10 dB.

Plot 3 shows a set of R_t contours that present negligible interference. For both heavy rain and clear days, the transmit power is minimum. The contour foot print for clear days is smaller than the foot print of rainy days.

In terms of these three plots, one can conclude that the constant transmit power control scheme never can meet the minimum interference requirement. If the interference is predictable and constant then the performance of ATPC and A_dTPC are identical. In terms of operational convenience, A_dTPC does not require interference prediction to maintain minimum transmit power. In practice, the interference level is never constant under all conditions even though the interference source is constant. For this reason, the only scheme that maintains the minimum transmit power is the A_dTPC scheme.

5. FREQUENCY AND POLARIZATION DISCRIMINATION

As mentioned earlier, increasing transmit power is not always the optimum solution to overcome interference. Alternative solutions are changing link polarization or frequency assignment. However, the effectiveness of these alternatives is inversely proportional to the percentage of usage. For example, if every links' polarization or frequency assignment is changed, then the interference in the network has not changed.

6. CONCLUSION

This paper has reviewed the two key parameters for interference control, namely the antenna pattern and transmit power control, and two parameters to overcome or avoid interference, namely frequency and polarization discrimination. For dense radio deployments, radios must have high performance antennas and minimize transmitted power. Polarization and frequency discrimination may be used with discretion in the hot pots.

7. REFERENCES

1. Dan Gulliford, David Oltman, John Carter and Peter Chow, "Consecutive Point Architecture for Broadband Wireless Access Networks," (This issue)
2. Federal Communications Commission, "Directional Antennas," FCC part 101.115, page 673, Revised as of Oct. 1, 1998

3. R.K. Crane,"Predition of Attenuation by Rain," IEEE Transactions Communications, Vol. Comm-28, No.9,1980, pp.1717-1733.
4. National Spectrum Management Association (NSMA), " Automatic Transmit Power Control (ATPC)," Recommendation WG18-91-032.
5. P. E. Chow, "Transmit Power Management," Triton Network Systems Inc., internal white paper, SY-SPE-122.
6. P. E. Chow, "IFU Network Design Guideline," Triton Network Systems Inc., white paper.

Table 2 FCC Required and High Performance Antenna Patterns

Sidelobe angle in degree	Antenna discrimination in dB	
	FCC	High Performance
0 to 2.5	0	0
2.5 to 5	0	25
5 to 10	25	25
10 to 15	29	37
15 to 20	33	37
20 to 30	36	37
30 to 100	42	43
100 to 180	55	55

Table 3 Antenna Discrimination versus Two Link Angles

Antenna discrimination in dB	Signal and interference path direction relationship in degrees					
	Mainbeam to mainbeam		Mainbeam to sidelobe		Sidelobe to Sidelobe	
	FCC	HP	FCC	HP	FCC	HP
40	N/A	N/A	0/30	0/30	5/5	2.5/2.5
50	N/A	N/A	0/100	0/100	5/5	2.5/2.5
60	N/A	N/A	N/A	N/A	5/20	2.5/10
70	N/A	N/A	N/A	N/A	10/30	10/10
80	N/A	N/A	N/A	N/A	5/100	10/30

Table 4 Cumulative antenna discrimination distribution for two randomly placed links

Antenna Discrimination in dB, larger than	Cumulative distribution of antenna discrimination in dB	
	FCC compliant	High Performance
40	0.991	0.996
50	0.969	0.985
60	0.941	0.971
70	0.907	0.929
80	0.818	0.917

Table 1 Relative Link Direction versus Antenna Discrimination

Relative link direction	Antenna discrimination
Main beam to main beam	0
Main beam to sidelobe	$G_{ab,cd}$ or $G_{ba,dc}$
Sidelobe to sidelobe	$G_{ab,cd} + G_{ba,dc}$

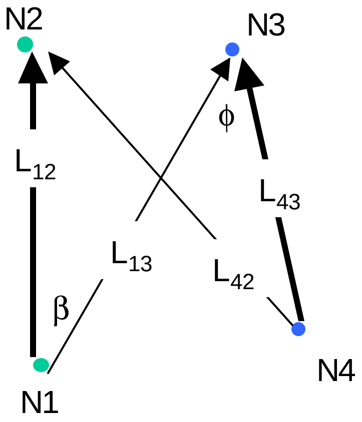

Fig. 1 Two radio link configuration

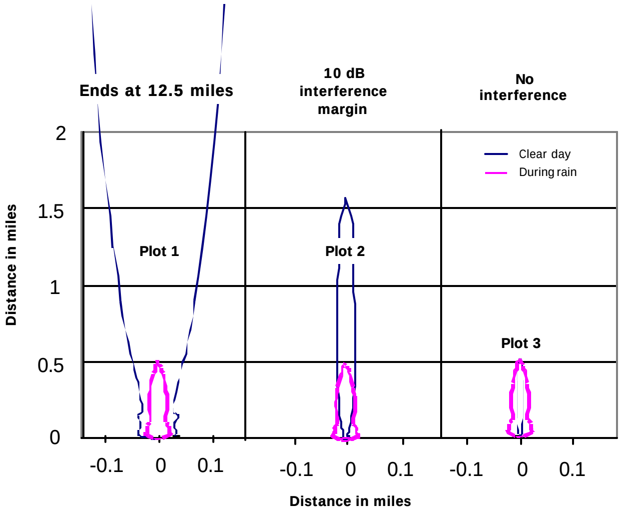

Fig. 2 R_t contour plots