Method for Achieving Optimum Downlink Capacity in the Deployment of a Wireless Network

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***Abstract*-Radio systems are emerging that deliver packet data over-the-air with variable data rates and varying delay requirements. This paper presents a new link budget methodology applicable to the downlink of such systems. These radio systems have several key attributes, for example no downlink power control and best server selection that enable the new link budget methodology. The important design metrics are range and capacity, where we define capacity as the amount of data throughput the system can deliver. The new link budget methodology ensures optimum capacity is achieved by the use of a definition of what we term the interference margin.**

Keywords -link budget; capacity

I. INTRODUCTION

This paper presents a new methodology for calculating the downlink link budget of a variable data rate, variable delay packet data radio access system. The aim of this new link budget methodology is to design a system that is capacity maximized – because high capacity cell sites are required to deliver the advanced, multi-media traffic of the future. Multi-media in this context is a general term used to denote that the communication content between the network and the user will have varying requirements, depending on the service being delivered. A sub-set of possible services includes: voice, web browsing, file transfer, audio or video streaming, gaming, secure transactions and text.

II. SYSTEM DESCRIPTION

Most high capacity radio access systems are interference limited. This is because of the desire to provide service to more and more subscribers in a limited amount of frequency spectrum with as few cell sites as possible.

This new link budget methodology is applicable to any radio access scheme that has the following important attributes.

A. Radio Access Scheme Description

- No power control. Base stations transmit full power, continuously. Variable rates can be achieved through adaptive modulation and/or variable code rates.
- Best server selection – the UE (user equipment) requests transmissions from the base station with the strongest received signal.
- All base stations use the same carrier frequency (i.e. so-called N=1 frequency re-use). Adaptations of this method could be exploited for different frequency re-use schemes. However, for simplicity N=1 only is considered herein.
- Time Division Multiple Access (TDMA): each user is granted a timeslot based on the measured channel, required data rate etc. For simpler analysis equal time-slot per UE is assumed. However, advanced schedulers can be used to increase throughput, increase aggregate capacity and provide varying QoS.

Note that the radio access scheme is similar to that described in [1].

III. THE TRADITIONAL LINK BUDGET APPROACH

Traditional downlink link budgets (CDMA, TDMA etc.) calculate the maximum range (distance between base station and UE) by considering UE received interference and noise parameters and the desired received signal level together with the available transmit power (EIRP) from the base station. The maximum allowable path loss is then the difference between the EIRP and the desired received signal level (taking into account UE antenna gain). The subtraction of several 'margins' from this maximum allowable path loss are required, the most significant of which is the shadow[1] fade margin. The shadow fade margin is used to ensure that a desired percentage of the cell is 'covered' (i.e. has a signal strength that will enable the desired service to be obtained). Once the resultant path loss has been found, that is the maximum allowable path loss minus all margins, this is then used in conjunction with a propagation model to calculate the distance or maximum range of the cell. For example, a (single

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[1] Shadow, shadowing; is the description given to large-scale path loss variability typically associated with buildings. Shadowing is modeled as a normally distributed, on a log scale, random variable – lognormal shadowing.

slope) propagation model for the median path loss may take the following form:

$$\text{path\_loss(dB)} = \text{K1} + \text{K2} * 10\log_{10}(\text{distance}) \qquad (1)$$

This traditional link budget approach was fine for 2nd generation systems, where typically only one data rate was available (to provide voice service). However, for systems with a multitude of data rates (implying differing SNR requirements), then the link budget has to be calculated separately for each data rate. Hence several link budgets are produced, and an operator must then decide for which data rate/coverage to dimension the cells. Using this traditional method it is not clear whether the optimum capacity has been achieved.

IV. THE PROPOSED LINK BUDGET APPROACH

The new link budget methodology, which we describe below, is much simpler to implement for the multi-data rate system (with attributes defined in Section II) and ensures that the appropriate trade-off between capacity and range is made clearly and explicitly.

A. Path Loss Calculation

First, to ensure capacity is maximized, the system must be designed to be interference limited. To do this we need to calculate the amount of interference power received at the UE. This has to be done using a Monte-Carlo type simulation, since the UE position within the cell is random, as is the shadowing from any base station to the UE. The interference power is the (non-coherent) sum of received signal powers from all transmitting base stations in the network, minus the strongest received signal power (which is chosen to be the serving signal). Choosing the strongest signal power is accomplished with advanced measurements and signaling as highlighted in the brief description of the radio system. Fig. 1 shows the simulation set-up used to carry out this Monte-Carlo simulation. The simulation also contains parameters associated with the lognormal shadowing and the median path loss (1).

The result of the simulation is the production of the cumulative distribution function of received interference powers for a given base station spacing and base station transmit power, as shown by way of example in Fig. 2.

To ensure a robust statistical measure of the interference power, we chose the median[2] interference level as our metric. Since we know the base station transmit power, we can calculate the effective path loss to the median interference power, as simply:

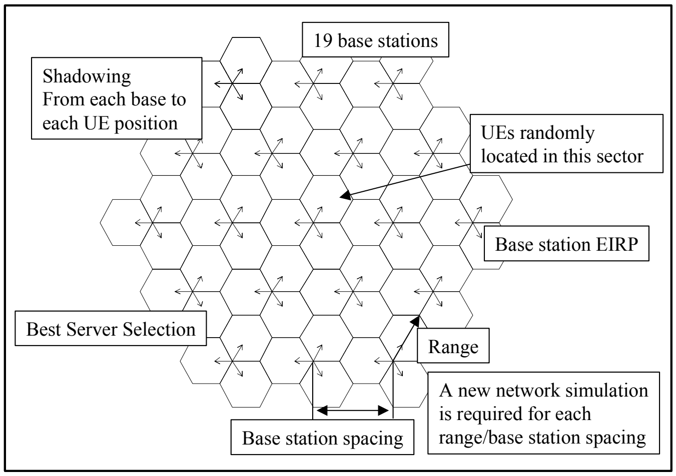

Figure 1.Simulation configuration.

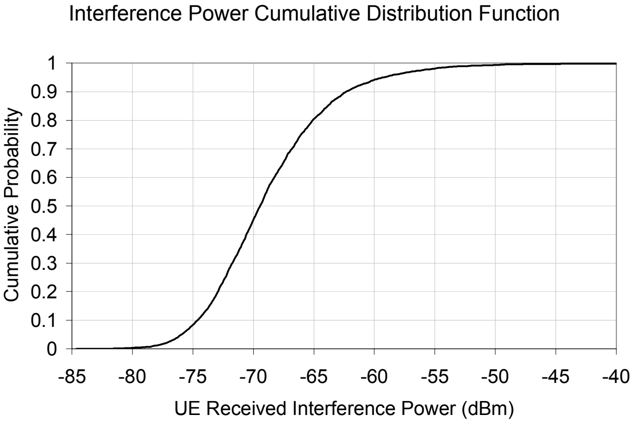

Figure 2. Result of one simulation, the cumulative distribution function of the received interference power.

$$\text{path\_loss\_interference(dB)} = \text{Ptx} - \text{mip} \qquad (2)$$

Where, Ptx is the transmitted power (EIRP) and mip is the median UE received interference power.

At this point, we make a couple of important observations.

1. The path loss in (2) is the statistical combination of path losses from all base stations to all UEs, for a given base station spacing. It is not a simple point-to-point path loss as in (1).

2. The path loss in (2) implicitly includes shadowing within the network. This is because the strongest signal power is chosen as our server – best server selection. The notions of area coverage and shadow margin are hence not required.

By repeating the simulation for several base station spacings, a graph, or look-up table, can be constructed relating path loss to the median interference power level vs. Base station spacing (or range), for example see Fig. 3.

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[2] The choice of median is not a mandatory requirement for this method, but represents a convenient, easy to calculate and statistically stable metric. Median is defined as the point where 50% of the data samples lie above the median value and 50% lie below the median value.

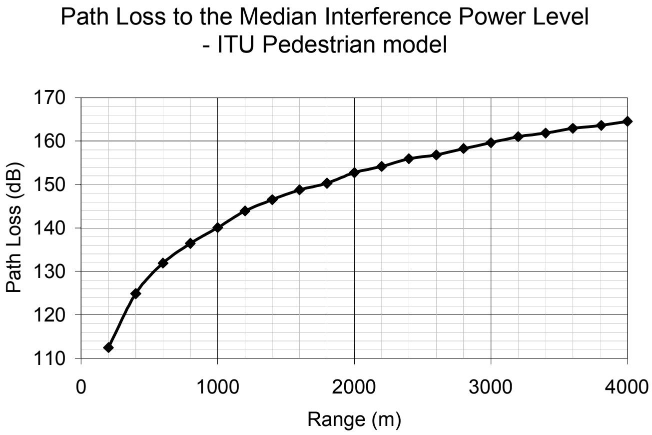

Figure 3. Network simulation results showing the path loss to the median interference power level (ITU Pedestrian propagation model used).

So far we have described the first part of the new link budget methodology. The second part is to calculate the capacity for a specified interference margin, and show the trade-off of capacity vs. interference margin. The interference margin is a new term that measures how much the median received interference power is above the thermal noise power at the UE. The received interference power is linearly related to the base station transmit power (since in our radio access system all base stations transmit full power) and hence the interference margin is also linearly related to the base station transmit power.

B. Capacity Calculation

In the radio system briefly described, the coding and modulation are set according to the UE received CNIR (carrier to noise plus interference ratio) on a case-by-case basis. Each UE in the network will experience its own, different, CNIR, due to proximity to neighboring base stations and the random shadowing. Hence each UE will be served with a different data rate. For those UEs where the CNIR is high, a modulation and coding scheme with high bit loading can be used to increase the data rate or throughput to the UE. In the radio access system, the long-time average throughput is given by the UE data rate multiplied by the access time. For simple capacity analysis, the access time to made equal for all UEs, the so-called 'Round Robin Equal Timeslot' scheduling assumption[3]. The capacity is then simply the weighted sum of data rates, as in (3) below, where $\boldsymbol{p_i}$ is the probability that data rate $\boldsymbol{R_i}$ is received. The probability $\boldsymbol{p_i}$ is determined by the CNIR probability distribution function, see [2] for example.

$$Capacity = \sum_{i=1}^{N} p_i . R_i \tag{3}$$

As the transmit power from the base stations increases, the CNIR increases. In the limit this CNIR will increase to the point that interference dominates over noise, and CNIR~CIR. This is the point at which maximum theoretical capacity is achieved. Of course, increasing the transmit power indefinitely is not an option. Moreover an increase in transmit power (or equivalently an increase in interference margin) does not increase the CNIR linearly. This is clearly shown with the aid of Fig. 4 below. Two curves are shown in Fig. 4, SNR and CNIR (at the UE) as a function of transmit power (from the base station) for a UE whose location and random shadowing allow a maximum achievable CIR of 5dB. In the limit, when each UE is operating at it’s maximum achievable CIR the maximum theoretical capacity is achieved. To complete the analysis we need the relationship between capacity and transmit power (interference margin).

To calculate the capacity as a function of the interference margin we perform another Monte-Carlo type simulation. For each interference margin (or transmit power) the CNIR distribution (over all UEs) is calculated, and the resulting capacity using (3) is also calculated. This is repeated as a function of increasing interference margin. The result is a curve like that shown in Fig. 5 below.

We can now design our system to support a specified capacity, and from this we can determine the required interference margin. From the interference margin, we use a link budget to calculate the transmit power required to support a certain base station spacing. Alternatively, we can calculate the maximum allowable base station spacing for a specified transmit power.

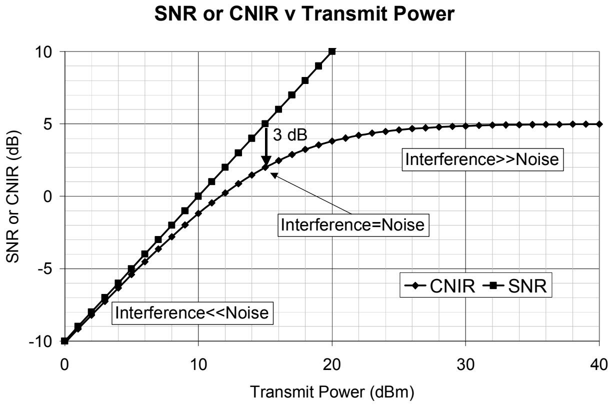

Figure 4. Example for one UE; received SNR and CNIR, in the limit CNIR -> 5dB.

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[3] The allocation of access time is an area where advanced schedulers can be used to tailor the capacity/data rates according to an operator’s business objectives.

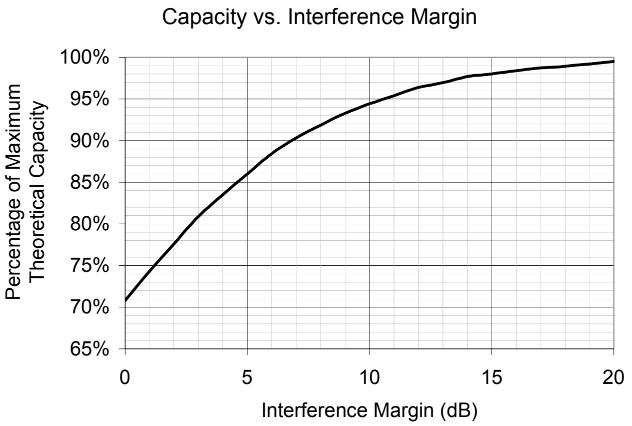

Figure 5. Capacity as a function of Interference Margin.

C. The Link Budget

Finally, we calculate the downlink link budget itself. As previously mentioned we will make use of the new term - the interference margin. The interference margin (IM) is the difference between the median interference power received and the UE receiver thermal noise power (UE_noise);

$$IM = mip - UE\_noise \tag{4}$$

In (4), the UE received thermal noise power is calculated in the normal way, taking into consideration, UE noise figure, operating temperature and signal bandwidth. The median interference power is set by the interference margin – the design parameter.

The median interference power is then used to determine, for a given base station transmit power, what is the maximum cell range. This is done by use of the previously described look-up table relating path loss to the median interference power level vs. base station spacing (or range).

The new downlink link budget technique described herein can be summarized as follows:

1. Produce look-up table (or graph) of path loss to median interference power v Range (e.g. Fig. 3). This requires simulation with a fixed tx power and varying range/base station spacings, with 19 base stations in the network, median path loss and shadowing models etc.

2. Choose a desired interference margin. This requires a sensitivity analysis of capacity v interference margin, which is done at a fixed base station spacing, by varying the transmit power.

3. Produce link budget to determine PA power/range.

Steps 2 and 3 can be repeated easily to provide the capacity/transmit power/range trade-off.

The link budget can now be used to ensure optimum choice of the base station transmit power for a given range. For example it may be determined that the uplink limits the range. Hence for a specified range and capacity an adequate transmit power can now be calculated. This is particularly important with advanced cell sites that may have multiple transmit paths per sector, as with MIMO. Thus care is required to ensure that the transmit power is not needlessly over specified.

V. SIMULATION RESULTS

An example of how this methodology can be applied to perform the PA power requirement / Range and capacity trade-off is shown in Table I. All the values chosen in Table I are representative of typical values used in base stations and UEs, and are not specific to any product or standard (the bandwidth of 5 MHz was chosen arbitrarily).

An interference margin of 10 dB has been chosen which corresponds to a capacity of 94% (see Fig. 5) of the theoretical maximum.

TABLE I. EXAMPLE DOWNLINK LINK BUDGET, ASSUMING AN ITU PEDESTRIAN PROPAGATION MODEL.

Base station	Equation	Value	Units
PA output power	a	40	dBm
Duplexer Loss	b	1	dB
Cable Loss	c	3	dB
Antenna Gain	d	16	dBi
EIRP	e=a-b-c+d	52	dBm
UE Receiver			
Bandwidth	f	5.00	MHz
kT	g	-174	dBm/Hz
Noise figure	h	9	dB
Noise floor	i=g+10*log10(f)+h+60	-98.0	dBm
Antenna Gain	j	0	dBi
Interference margin	k	10	dB
Median Interference power	l=i+k	-88.0	dBm
Path loss and Range			
Path loss to median interference level	m=e-l	140.0	dB
Range (from Fig. 3)	n=Range(m)	1.0	km

VI. SUMMARY

To summarize, the radio access scheme described is better engineered by employing a new link budget methodology. The new link budget methodology allows the capacity to be specified explicitly. It is then a simple matter to perform a transmit power / base station spacing calculation. By using the new metric - the interference margin, capacity/transmit power/base station spacings can be optimized or traded.

REFERENCES

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