Joint Analysis of Traffic and Channel Power Distributions in 3G Wireless Telecommunications Networks

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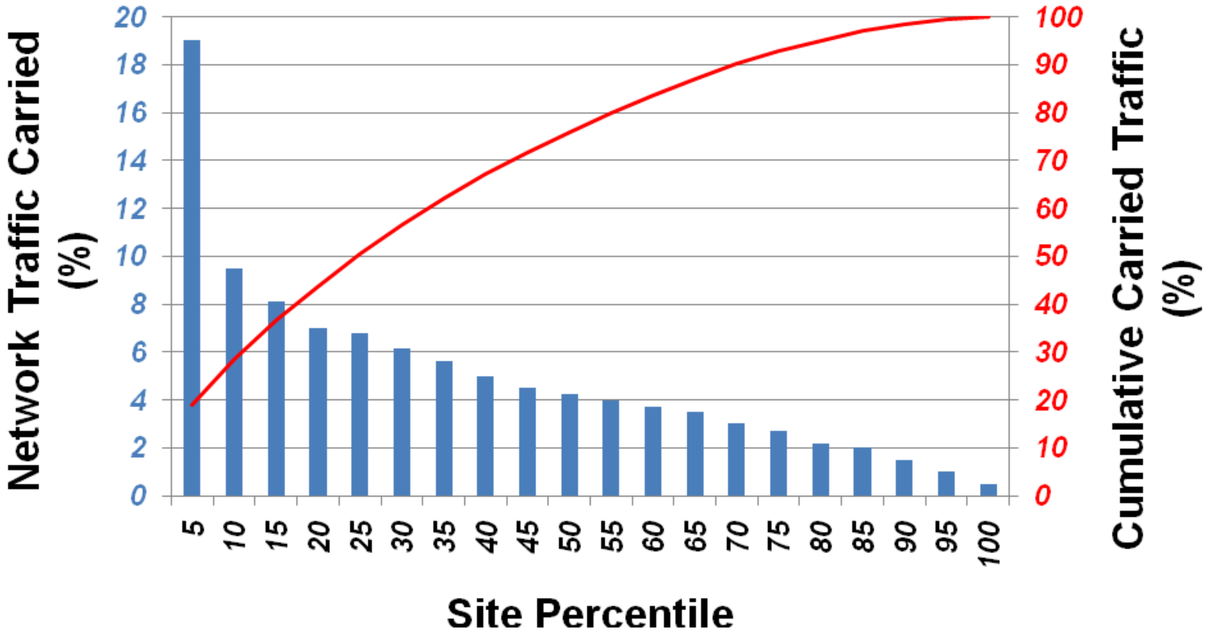
Providing capacity to keep pace with the explosive growth in wireless data services is a highly complex task, due to the time variant and geographically inhomogeneous nature of offered traffic. To ensure a consistent, high-quality user experience, both site and carrier density must be tailored to match the offered traffic density, with sufficient margin to accommodate large fluctuations in traffic loading.

This task is further complicated by the presence of interference, which is typically distributed randomly both in location and time. The net effect of interference is to consume the design margin intended to accommodate variations in traffic; in those instances where interference coincides with dense traffic, severe service impairments under heavy load are typically the result. In this technical note, we discuss the statistical distributions of traffic and interference from a network perspective, and how poor correlation between measured traffic and uplink channel power can be used to assess interference severity.

Network Loading Is Highly Concentrated

Figure 1 illustrates the distribution of traffic, ranked vs. site percentile from highest to lowest in 5% bins, for a typical urban 3G wireless network. If site coverage perfectly matched the geographical distribution of offered traffic, each bin would carry the same fraction of the total network traffic and the histogram would appear uniform. The actual distribution, however, is highly skewed: Sites in the first bin (the busiest 5% of sites) carry 19% of the total network traffic, and the busiest 25% carry fully half of the total traffic.

Figure 1: Total percentage of network traffic carried vs. site percentile.



The obvious conclusion is that *the performance of a small number of sites dominates the aggregate performance of the entire network*. These sites are simultaneously critical in terms of customer perception of the quality of the network, and least able to deal with interference due to the small residual link budget margin present in highly loaded sites.

The Relation Between Loading and Channel Power

Loading in CDMA systems is typically monitored by measuring the uplink channel power by sector-carrier. In a network free from external interference, the total channel power (in 3GPP defined as Received Total Wideband Power, or *RTWP*) is simply

$$RTWP = P_{ic} + P_{oc} + N_0, \tag{1}$$

where P_{ic} is the in-cell multi-access power transmitted by other users, P_{oc} is the multi-access power transmitted by users in other cells, and N_0 is the thermal noise floor for the measurement bandwidth[1]. The *noise rise* is the ratio of the measured channel power to the thermal noise floor, and is related to the total cell loading by

$$NR = \frac{RTWP}{N_0} = \frac{P_{ic} + P_{oc}}{N_0} + 1 = \frac{1}{1 - \eta_{UL}}, \tag{2}$$

where η_{UL} is the *uplink load factor*. It is obvious that

1. In the absence of external interference, the *RTWP* observed is directly determined by the subscriber load on the site (traffic and *RTWP* are perfectly correlated),
2. As η_{UL} approaches 1, noise rise and the *RTWP* become arbitrarily large.

Since margin for noise rise must be accounted for in the link budget, it is crucial that loading be managed such that noise rise, including all fluctuations due to offered traffic density variations, is kept within the original design bounds if the site coverage area is to be maintained.

An example complementary cumulative distribution function (CCDF) of the mean busy-hour *RTWP* for all sites in a large network is shown in Figure 2. The result in blue reflects the traffic only (external interference-free) case discussed above[2]. The site traffic density can be broadly classed as follows

1. Low traffic (max *RTWP* < -97 dBm)
2. Moderate traffic (max *RTWP* < -93)
3. High traffic (max *RTWP* < -90)
4. Special event traffic (max *RTWP* < -82)

Loading a site to an RTWP above -90 dBm (*NR* =13 dB) is typically not sustainable due to the instabilities in the coverage area that result, except in the case of special event venues (*e.g.* stadiums, arenas, race tracks, *etc.*) where traffic is kept in a tightly confined area and coverage is not a concern.

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[1] For 3GPP RTWP channel bandwidths,
$N_0 = -174\ \text{dBm/Hz} + 10\log_{10}\left(3.84 \times 10^{6}\ \text{Hz}/1\ \text{Hz}\right) = -108\ \text{dBm.}$

[2] The minimum observable *RTWP* is -103 dBm due to the assumption of a 5 dB system noise figure.

Evidence of Interference in the *RTWP* CCDF

The presence of interference adds an additional term to the total power in the channel

$$RTWP = P_{ic} + P_{oc} + P_i + N_0, \tag{3}$$

where P_i represents the total amount of co-channel interference present, and equation 2 becomes

$$NR = \frac{RTWP}{N_0} = \frac{P_{ic} + P_{oc} + P_i}{N_0} + 1 = \frac{1}{1 - \eta_{UL}} + \frac{P_i}{N_0}, \tag{4}$$

so from the perspective of a single *RTWP* measurement, co-channel interference from external sources is indistinguishable from noise rise due to traffic loading.

The effect of the additional co-channel interference term[3] in equation 4 on the busy hour *RTWP* CCDF is shown in gray in Figure 2. The most obvious effect is the addition of a high power tail to the *RTWP* distribution, with a 1% chance to exceed -80 dBm. These levels are extremely unlikely due to traffic alone and are a strong indication of external interference. At -92 dBm (10% likelihood to exceed), the curve incorporating an interference component begins to diverge from the curve for traffic loading alone, and as low as -95 dBm interference can be a substantial component of the total recorded RTWP. In these cases, joint analysis of the maximum *RTWP* and the concurrent traffic on the site can be used to identify the presence of interference, since high *RTWP* to carried traffic ratios are also a strong indication of external interference.

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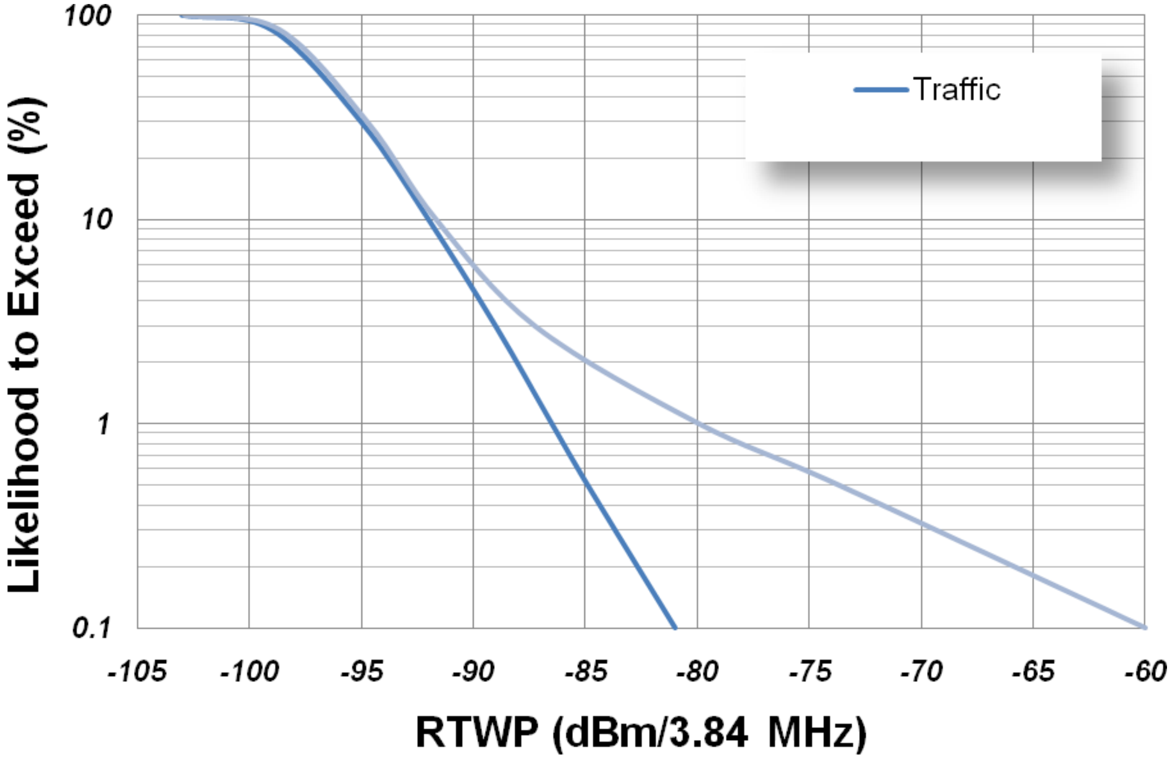
[3] Interference is modeled with distributions in both power and location.

Figure 2: Network-wide complementary cumulative distribution function (CCDF) of busy hour RTWP, by sector-carrier, as expected from traffic alone and with an interference component. A 5 dB net system noise figure is assumed.



Interference Awareness: A Vital Component for Ensuring Network Performance

Interference is a pervasive problem, and as networks strain to handle the current dramatic growth in wireless data traffic, the importance of identifying and resolving performance degradation due to interference is growing more acute. Traditional approaches address severely impaired sites on a case-by-case basis, and are often identified by customer complaints of poor service quality. Applying a more network centric approach, by jointly analyzing *RTWP* and traffic loading distributions to identify potential trouble sites, represents a more proactive approach to interference management that allows operators to identify RF impairments before they turn into customer complaints.