AT&T/T-MOBILE: FURTHER ANALYSIS OF CAPACITY, SPECTRUM EFFICIENCY AND SERVICE QUALITY GAINS FROM NETWORK INTEGRATION

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In a previous paper submitted to the FCC, we explained that very substantial gains in spectrum capacity, efficiency and network performance can be achieved by integrating the AT&T and T-Mobile USA networks. These gains arise from a variety of mechanisms: increased cell density, channel pooling, the elimination of redundant control channels, and better network utilization, each of which not only directly increases available capacity but also enhances the ability to shift spectrum from less to more spectrally efficient technologies, providing further capacity gains. As we explained, the *existence* of each of these types of integration-related efficiency gains is well-accepted and uncontroversial. As a matter of basic cellular engineering principles, (i) the combined company will have considerably greater spectrum capacity than the sum of the two companies' standalone capacities, (ii) spectrum will be used more efficiently, and (iii) both companies' customers will enjoy better service quality.

The purpose of this paper is to elaborate on some of the points we made previously and to provide more precise estimates of the projected gains based on more detailed engineering analyses that we and AT&T have performed on additional real-world data from the AT&T and T-Mobile USA networks. After examining market-specific data from the two existing networks, reviewing ongoing AT&T integration analyses that identify the specific T-Mobile USA cell sites that can be productively assimilated into the AT&T networks, and performing more detailed, sector-level calculations, we can confirm that the network integration benefits would be even more significant than we or AT&T previously predicted. The actual network integration analysis of San Francisco proper, for example, demonstrates that more than **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** of the T-Mobile USA sites in that area can be productively integrated into the AT&T network, and that this cell splitting will, in fact, provide very substantial capacity and coverage improvements in high traffic areas where most needed. We have also performed more detailed channel pooling, control channel and utilization calculations that likewise confirm that the achievable gains from each of those efficiencies will meet or exceed the companies' previous estimates.

It bears emphasis at the outset that each of the efficiency gains we discuss here will directly relieve *UMTS* capacity constraints. This is most obvious with respect to the "cell splits" that will be accomplished through the initial integration efforts. At the thousands of T-Mobile USA cell sites that can productively be assimilated into the existing AT&T cell grid, the existing T-Mobile USA antenna will be replaced with a multi-band antenna that will operate at a variety of carrier frequencies (*e.g.*, 850 MHz, 1900 MHz, AWS and 700 MHz spectrum), and the site will be equipped with 3G radios that operate on AT&T's UMTS spectrum frequencies. The AT&T UMTS cell grid will thus become much more dense with the assimilation of the T-Mobile USA sites, and AT&T's UMTS network will, accordingly, have much more capacity. In other words, at each location where a T-Mobile USA site is assimilated, an AT&T UMTS cell split that creates substantial additional capacity automatically takes place.

The increase in capacity occurs because each cell site in a cellular network uses the full amount of spectrum that the carrier has operationalized in the area. Put most simply, replacing one larger UMTS cell with two smaller cells effectively doubles capacity in that area (because the same spectrum is now used twice, instead of once, in that area). In fact, as we explain further below, there will be additional capacity gains even beyond the capacity doubling impact of spectrum reuse: increasing cell density can also improve signal quality, thereby increasing achievable UMTS spectral efficiency (the amount of traffic/MHz of deployed spectrum that a cell can handle). The capacity of AT&T's UMTS network will automatically increase as AT&T integrates T-Mobile USA cell sites into its existing grid, a process that we understand will begin in the areas that are most capacity constrained. No spectrum must be added or "cleared" and no customer handsets must be replaced to create this automatic UMTS capacity increase, which will be immediately available to serve existing and new AT&T UMTS customers and (also T-Mobile USA UMTS customers with dual-band handsets). Moreover, the assimilated T-Mobile USA sites will, by definition, be in areas where AT&T needs UMTS cell splits, because the engineering analyses that AT&T is performing to determine which T-Mobile USA sites to assimilate *are UMTS engineering analyses* specifically designed to identify the T-Mobile USA sites that will best address UMTS capacity, performance and coverage issues.

The initial network integration will, of course, also increase UMTS capacity less directly (but quite substantially) by accelerating spectrum migration from GSM and thereby supplying large amounts of additional spectrum to the UMTS network. It is important to understand that there are no "2G only" network efficiencies; improving 2G network efficiency increases UMTS capacity by accelerating the repurposing of spectrum from 2G to more spectrally efficient UMTS networks. And because UMTS is much more spectrally efficient than 2G GSM technologies – the same block of spectrum can carry many more voice calls and megabytes of data when it is deployed on a UMTS network relative to its carrying capacity when deployed on a 2G GSM network. As a result, capacity gains that first materialize on the 2G network are greatly magnified as the spectrum those capacity gains free up is moved to UMTS.

Here, those gains – and the resulting UMTS capacity boost – extend beyond increased cell density; rather, all of the 2G customers and traffic will be consolidated on a single, more efficient 2G network. Several capacity-enhancing efficiencies necessarily follow, as a matter of basic cellular network engineering principles:

- *Channel Pooling.* When two carriers combine their GSM spectrum and customers, it is a mathematical fact that the combined company will not need as many transceivers and radio channels to serve those customers at the same call quality. Because transceivers consume spectrum resources, these efficiencies will immediately free up significant amounts of spectrum that can be repurposed for the UMTS network. This remains true even in areas where both networks are heavily loaded. We previously estimated that the combined company could expect 10-15 percent gains in spectrum capacity from channel pooling alone. For this paper, we have examined sector-level data from AT&T's and T-Mobile USA's nationwide networks, and we can now report that channel pooling gains are likely to be within – or in certain circumstances well above – this range.

- *Control Channels*. Today, both companies devote significant amounts of spectrum to control channels – *i.e.*, "overhead" channels that manage the transport of network-related information between the base station and user devices. When the two networks are merged, however, many of these control channels will become redundant and can be eliminated. As shown below, in many cities this efficiency alone could free up close to 10 MHz of spectrum for UMTS services.

- *Network Utilization/Load Balancing*. The combined GSM networks will also benefit from utilization or load balancing efficiencies. Demand on any cellular network is "lumpy" in the sense that some areas may experience very high demand relative to other areas. In areas where T-Mobile USA's (or AT&T's) network is relatively lightly loaded, combining the two customer bases on a single network will allow the combined company to repurpose more spectrum to target UMTS capacity constraints. In **[Begin Confidential Information]** **[End Confidential Information]**, for example, our review of sector-level data confirms that T-Mobile USA's GSM network **[Begin Confidential Information]** **[End Confidential Information]**. But even in a market where both networks are, *on average*, fairly heavily loaded, each network will, *within that market*, have a different "map" of traffic peaks and valleys, and combining the two customer bases on a single network thus smoothes out peaks and valleys and provides load balancing efficiencies that may enable additional repurposing of spectrum.

In addition, there will be still further capacity gains from increased cell density where AT&T equips the retained T-Mobile USA sites with compatible 2G radios. **[Begin Highly Confidential Information]** **[End Highly Confidential Information]**. Each of these integration benefits is a UMTS efficiency, because it directly contributes spectrum to the UMTS networks that would otherwise have been necessary to serve the GSM customer bases. Each is a "1+1=3" capacity enhancement that ensures that the combined company will have more total capacity than the sum of the capacities of the two standalone companies. The cumulative gains from these efficiencies can be very substantial. Based upon the detailed network integration work AT&T has completed for the area of San Francisco it has studied, for example, we estimate that when all of the network efficiencies are factored in, the combined company will be able to transfer to UMTS **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** of spectrum used by the standalone companies for GSM – even without altering the total number of GSM customers served.

Cell Splitting. AT&T's initial engineering analysis indicated that about **[Begin Confidential Information]** **[End Confidential Information]** of the T-Mobile USA cell sites (or approximately **[Begin Confidential Information]** **[End Confidential Information]** total sites) would be complementary to AT&T's existing cell grid and could be productively integrated to create a combined network with a much denser cell grid. AT&T based its analysis on experience with other network integrations and conservative cell site spacing distance proxies.

Critics of the merger have complained that AT&T cannot know precisely which sites will be complementary – and can be productively integrated to address existing and projected capacity and coverage needs – until it conducts the detailed site-by-site engineering analyses that precede any network integration. AT&T's initial analysis based on its prior integration experience was designed to provide a conservative estimate of the *total* number of T-Mobile USA cell sites likely to be integrated into the combined network. As we have previously discussed, there are sound engineering reasons to believe that the actual site specific engineering work that precedes network integration will yield at least as many complementary sites that address real world capacity and coverage issues as the distance proxy (although not necessarily *every* site that matched the distance proxy will be kept and many that did not match the distance proxy will be kept).

Indeed, AT&T's initial distance-based analysis is likely to *understate* the number of T-Mobile USA cell sites that can be productively retained, because in areas that are particularly traffic-intensive, good engineering practice can support cell densities significantly higher than implied by the initial analysis (which, we understand, generally focused on T-Mobile USA sites more than **[Begin Confidential Information]** **[End Confidential Information]** from existing AT&T sites). In these high traffic areas where base stations are more likely to be close to one another, the initial approach eliminates many of the base stations that a more detailed engineering analysis would keep. These are exactly the types of base stations that will provide valuable extra capacity and that will be picked up in the ongoing, site-specific network design and optimization analyses. This is uncontroversial: we note, for example, that Sprint's wireless engineering report in the FCC merger proceeding states that cell radii much smaller than implied by **[Begin Confidential Information]** **[End Confidential Information]** spacing between sites may be beneficial in urban areas.

Nonetheless, to provide further confirmation of the magnitude of the cell-splitting opportunities, AT&T tasked its engineers with conducting, for large areas of several markets, the same types of engineering analyses that they conduct during actual network integration. **[Begin Highly Confidential Information]**

[End Highly Confidential Information]. AT&T has described this methodology, which reflects the UMTS design guidelines AT&T uses in the ordinary course of its business, in a separate paper that we have reviewed. We have also reviewed AT&T's completed integration work for large areas of the cities of San Francisco and Los Angeles, as well as sample outputs from ongoing engineering analyses for other cities. We are not surprised that these more detailed analyses strongly confirm the conservatism of AT&T's initial estimates of the number of T-Mobile USA cell sites that can be productively assimilated.

In San Francisco, for example, the site-specific engineering analyses have concluded that over **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** of the T-Mobile USA sites in the area studied can be productively integrated into the existing AT&T cell grid. In the large area of Los Angeles for which detailed engineering analyses have been completed, over **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** of the T-Mobile USA sites can be productively integrated. As we anticipated, many of the useful T-Mobile USA sites in these dense urban areas are closer than **[Begin Confidential Information]** **[End Confidential Information]** from existing AT&T cell sites.

In this regard, we have reviewed some of the very granular maps that the AT&T engineers conducting the network integration analyses have prepared that show quite clearly, with visual representations of well-accepted cellular engineering metrics, how individual T-Mobile USA sites will both provide substantial additional capacity where it is needed and address existing quality or coverage holes. For example, more than **[Begin Highly Confidential Information]**

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Furthermore, AT&T's detailed engineering analyses confirm that, as we would expect, signal strength and performance will improve for both AT&T and T-Mobile USA customers. The detailed engineering analyses demonstrate that the increased cell density enhances capacity by increasing "reuse" of the spectrum deployed in AT&T's UMTS network (simply as a matter of network architecture, each new cell can reuse the full capacity of the deployed spectrum to handle additional traffic so more cells automatically implies more capacity). Furthermore, the increased cell density can also improve signal quality within key areas of the cells, thereby creating a "cleaner" radio environment; the combined company will then effectively experience greater UMTS spectral efficiency and thus be able to carry more traffic within each of those cells (existing and added cells).[1] We have reviewed AT&T's preliminary estimates (using the Atoll

[1] It is typically assumed for a homogeneous UMTS network that the cell capacity is the same regardless of the cell size because the signal-to-interference ratio (SIR) effectively remains the same. SIR, which directly influences cell capacity in CDMA-based systems such as UMTS, is the ratio of the received signal power to the received interference power. UMTS power control ensures that the amount of power being allocated to the user meets the SIR requirements to ensure good quality of service. The downlink transmit power allocated to the user relative to the

tool, which supports sophisticated Monte Carlo simulations), and agree that even this latter, less obvious, benefit can be quite significant.[2]

Finally, the results of the actual network integration engineering are likely to produce similar benefits throughout the country. There are sound engineering reasons to expect that a high proportion of T-Mobile USA sites are located in high traffic areas where the additional capacity associated with integration will be most beneficial. T-Mobile USA's cell sites tend to be concentrated in urban population centers. T-Mobile USA has advised us, for example, that

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total power at the cell (or sector) is one of the critical factors that dictates the cell capacity. Since the transmit power in a sector is limited, higher transmit power per user implies lower capacity, and lower transmit power per user implies higher capacity. If SIR can be improved through network integration, less transmit power is required per user, increasing the cell capacity. **[Begin Highly Confidential Information]**

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[2] We worked with AT&T engineers on potential methods of separating pure cell-splitting gain from SIR improvement-related gain and performed this analysis on actual network data for the city of Chicago. The Atoll simulation results based upon the AT&T cell grid and the complementary T-Mobile USA cell sites identified by AT&T's engineering analyses in Chicago indicate that the overall capacity gain due to increased cell density is about **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** when the (call or service) rejection rate is about **[Begin Highly Confidential Information]** **[End Highly Confidential Information]**. The pure cell splitting gain is approximately **[Begin Highly Confidential Information]** **[End Highly Confidential Information]**, and the SIR-related gain is about **[Begin Highly Confidential Information]** **[End Highly Confidential Information]**. The same quality of service (quantified in the form of rejection rate in Atoll Monte Carlo simulations) was enforced for the pre-merger AT&T network, pre-merger T-Mobile network, and combined network during the simulations. We note that optimization of the integrated network could lead to even higher SIR-related gains. The improved SIR distribution can be explained as follows. When more sites are added to an existing network, users are relatively closer to cell-sites compared to a pre-merger situation. Hence, signal power increases. Distribution of Ec (*i.e.*, received pilot power) in the simulations confirmed a significant increase in the signal power. Of course, the overall interference in the system also increases as cell density increases. The overall SIR distribution improves when the signal power increases much more rapidly than the interference power. The pre-merger network layout and post-merger network layout influence the change in the SIR distribution. Improvement in SIR compared to the pre-merger AT&T network was evident in the form of (i) improved distribution of (Ec/I0) (which is the ratio of the received pilot power to the received total power including thermal noise) and (ii) lower per-user power. The results from the AT&T analysis prove that enhanced SIR resulting from a denser cell grid in a non-homogenous network can yield significant capacity gains.

nearly **[Begin Confidential Information]** **[End Confidential Information]** of its mobile wireless subscribers and nearly **[Begin Confidential Information]** **[End Confidential Information]** of its cell sites are located in the **[Begin Confidential Information]** **[End Confidential Information]** CMAs. T-Mobile USA's cell grid is also built to support the PCS and AWS spectrum used in its 2G and UMTS networks and therefore is relatively dense. Also, T-Mobile USA can be expected to have designed its network to locate base stations, to the greatest extent possible, in traffic "hot spots" – and since T-Mobile USA deployed its UMTS network relatively recently compared to AT&T and others, its design decisions could take account of experience with wireless broadband usage patterns.

Channel Pooling. The efficiency gains from channel pooling are also specific to the network integration facilitated by the merger and, based upon the real-world sector level data that we have now analyzed for a number of CMAs, these gains will be quite substantial (*e.g.*, often more than 15%). The gains from channel pooling flow from a well-accepted mathematical fact that has been validated over three decades of commercial cellular networks: combining the spectrum and radio resources of the two companies in a given area will allow the combined company to serve a larger average number of customers at the same target call blocking probability than the two companies could independently.[3] Although the percentage gains from channel pooling diminish as the size of the pool increases, our analysis shows that the vast majority of sectors in the combined network here have characteristics that will permit large gains from channel pooling – within or above the 10-15% range we and AT&T previously estimated.

Channel pooling in effect creates additional spectrum capacity, because the combined company can support a higher average number of simultaneous calls during the busy hour than the two companies could as independent companies. Cellular network engineers design their radio networks to ensure that subscribers can access and use the network successfully in the target service area even during peak traffic times – a cellular network is designed to have a sufficient number of channels so that the maximum target call blocking probability can be achieved during the busiest hour of the day. And, as we explained previously, the channel

[3] As we have explained previously, channel pooling gains can be quantified through the "Erlang-B" formulation, which is the relationship among (i) the total number of trunked channels (which, for GSM, is a function of the number of transceivers or "TRXs," and the relative distribution of full-rate and half-rate voice users), (ii) the Erlang capacity (which is the number of simultaneously active voice users), and (iii) the call blocking probability. The Erlang-B formulation is defined as:

$$P_b = \frac{\left(\frac{E^N}{N!}\right)}{\left(\sum_{i=0}^{N}\frac{E^i}{i!}\right)},$$

where P_b is the call blocking probability, N is the number of trunked channels (sector capacity), and E is the Erlang capacity.

pooling capacity gains will be achieved during the busy hour, when there is the greatest need for capacity (regardless of whether the absolute amount of traffic being carried is low or high).

In our original paper, we provided estimates of achievable pooling efficiency gains for a range of TRX assumptions, recognizing that the number of TRXs varies from one geographic area to the next and from one operator to another operator. For this paper, we asked AT&T and T-Mobile USA to provide sector-specific data on the actual number of TRXs deployed in their networks to allow us to more precisely quantify achievable channel pooling gains that account for their present network configurations. This granular, sector-level data shows that in the vast majority of sectors, the combined company will be able to achieve gains from channel pooling that meet or exceed the 10-15% levels that we and AT&T previously estimated.

Table 1 specifies the distribution of TRXs per sector for AT&T and T-Mobile USA. Notably, the vast majority of sectors – about **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** of the sectors – have **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** TRXs, which means that the vast majority of sectors have the characteristics in which gains from channel pooling will be relatively large.

Table 1. Distribution of TRXs Per Sector

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Using actual data from the AT&T and T-Mobile USA networks, the following table summarizes the pooling efficiency gains expected for the current network configurations of AT&T and T-Mobile USA.

Table 2. Expected Pooling Efficiency Gains for the Combined Network[4]
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As shown in Table 2, using actual data from the AT&T and T-Mobile USA networks, we have calculated the expected gain in Erlang capacity – *i.e.,* the gain in average number of

[4] We have used the average values of actual half-rate and full-rate voice distributions for thousands of sectors across the U.S. for AT&T and T-Mobile. AT&T has approximately **[Begin Highly Confidential Information]** **[End Highly Confidential Information]**. Since GSM operators and radio vendors choose a suitable rate based on capacity needs, it is apparent that AT&T's GSM network is more loaded than a T-Mobile network. Even after the merger, we have preserved pre-merger rate distributions of full-rate and half-rates for AT&T and T-Mobile for purposes of these pooling gain calculations, which significantly understates the total gains that will actually be achieved when all users and traffic are consolidated on the combined network at the AT&T **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** percentage.

subscribers that can be supported at the same call blocking probability – assuming different numbers of TRXs deployed in a given sector. For the **[Begin Highly Confidential Information] [End Highly Confidential Information]** of the sectors in which each operator has from **[Begin Highly Confidential Information] [End Highly Confidential Information]** TRXs, the additional gain in spectrum capacity from pooling ranges from **[Begin Highly Confidential Information] [End Highly Confidential Information]** more than the sum of the two networks' current capacities. In **[Begin Highly Confidential Information] [End Highly Confidential Information]** of the sectors, the number of TRXs per sector ranges from **[Begin Highly Confidential Information] [End Highly Confidential Information]**, and the efficiency gain in these sectors ranges from **[Begin Highly Confidential Information] [End Highly Confidential Information]**, with about **[Begin Highly Confidential Information] [End Highly Confidential Information]** of the total sectors experiencing a gain greater than **[Begin Highly Confidential Information] [End Highly Confidential Information]**. And **[Begin Highly Confidential Information] [End Highly Confidential Information]** of the sectors will experience gains from **[Begin Highly Confidential Information] [End Highly Confidential Information]**, which is *above* the range that we and AT&T previously estimated. The system-wide average pooling gain falls in the 10-15% range previously estimated.[5]

Furthermore, given AT&T's plan to retain in the combined network its own much higher (relative to T-Mobile USA) use of the "half-rate" speech codec for voice calls, the achievable capacity gains from integration are actually significantly higher.[6] Indeed, using actual AT&T and T-Mobile USA half rate/full rate data, we estimate that actual gains will significantly exceed our previous 10-15% estimate in **[Begin Highly Confidential Information] [End Highly Confidential Information]** sectors.

It is irrelevant that that the capacity gains from channel pooling are not needed at all times of the day – *e.g.*, at 2 a.m. What matters to the network engineer is the *peak* loads, because all cellular operators design their systems to have a sufficient number of radio resources during

[5] The average gain across all sectors is estimated to be **[Begin Highly Confidential Information] [End Highly Confidential Information]**. Furthermore, we observed that the small number (**[Begin Highly Confidential Information] [End Highly Confidential Information]** percent) of sectors that currently have **[Begin Highly Confidential Information] [End Highly Confidential Information]** TRXs per operator are scattered among markets and are not concentrated in a specific geographic area. In other words, the small number of sectors where the channel pooling gains are the smallest are dispersed among different markets and do not change the fact that the combined company can achieve large, system-wide, merger-specific spectrum capacity gains from channel pooling.

[6] GSM full rate service allows eight voice callers to share each radio channel (because each radio has eight time slots, each of which can accommodate one voice call). GSM half rate service allows 16 voice callers to share each radio channel (because each time slot can accommodate two half rate calls).

the busiest hour of the (busiest) day. Peak load demand will, of course, vary in different geographic areas, but whether it is the busy hour in Oklahoma or the busy hour in New York City, the goal is to ensure that subscribers experience the same call blocking probability. There will always be some busy hour for any geographic area and the network must have adequate resources to support the amount of traffic generated by subscribers during such busy hour. The bottom line is that with the larger channel pool enabled by the network integration, the same peak number of users can be supported at the same call blocking probability with *fewer* TRXs and radio channels dedicated to the GSM network. The need for fewer radio channels means that more spectrum can be repurposed to UMTS (and ultimately LTE) sooner.

It is also important to understand that channel pooling gains can occur *only* through the integration of two networks. In the absence of the merger, any attempt to increase capacity by adding TRXs to the standalone network (at significant cost) would not free up any spectrum that could be used for other services.[7] The important point is that the merger will allow the two companies to serve their combined customer bases with *fewer* radios (*i.e.*, fewer TRXs and radio frequency channels) and thus less GSM spectrum at each base station than they could as stand-alone companies – which increases efficiency and will accelerate the process of repurposing GSM spectrum for more spectrally efficient technologies.

Control Channels. We have also obtained additional data that allow us more precisely to calculate the spectrum savings from consolidating control channels. To summarize, in a cellular network, some radio channels are used to exchange user traffic (called "hopping" traffic channels) and some radio channels are allocated to "overhead" (called "control") channels. In a GSM network, control channels called Broadcast Control Channels (BCCHs) are overhead channels and can consume a significant amount of spectrum. When two independent operators

[7] In commercial GSM networks, a TRX uses a set of "hopping" radio channels for user traffic. Based upon experience, the network engineers determine the necessary ratio of hopping channels (each of which consumes 200 KHz of spectrum) to TRXs to achieve the target quality levels (*i.e.*, acceptable error rate, voice quality, and call drops). Frequency hopping provides gains associated with frequency diversity and interference diversity. The radio environment is dynamic, and different radio channels experience signal fading at different times and frequencies. If a TRX used a single radio channel at all times the user would experience poor quality communications when that radio channel experienced fading. However, since a TRX keeps hopping from one radio channel to another every frame, the user is not held hostage to the propagation conditions of a single radio channel – the user quickly comes out of a potential signal fade due to frequency hopping. Furthermore, different sectors use different pseudo-random patterns of frequency hopping. For example, one sector's TRX may hop from radio channel f1 to radio channel f5, but another sector's TRX may hop from radio channel f2 to radio channel f6. Due to such random frequency hopping patterns in different sectors, overall interference becomes more random and lower. When an operator increases the number of TRXs, the number of radio channels in the hopping pool (and thus the amount of spectrum allocated to the GSM network) is therefore also increased to maintain acceptable frequency diversity and interference diversity gains.

are covering a given geographic area, each operator reserves its own set of BCCH carriers, but if the two operators merge and integrate their networks, the combined company does not need both sets of BCCHs, and duplicate control channels can be eliminated.

Network integration can yield very significant control channel benefits in terms of spectrum capacity lift, because BCCHs consume significant spectrum. Although each cell uses only one 200 KHz channel for the downlink and one 200 KHz channel for the uplink, the same channels cannot be used in adjacent and nearby cells due to interference issues. Thus, depending upon the "frequency reuse plan" in an area (essentially how many cells must be skipped over before the same frequency channel can be reused for a BCCH), anywhere from 4.8 to over 10 MHz must be allocated to control channels.[8]

In our previous paper, we analyzed the gains from eliminating redundant control channels using typical frequency reuse ranges provided by AT&T and T-Mobile USA, and we concluded that the gains would range from 4.8 MHz to 10 MHz, depending on the frequency reuse plan.

More recently, T-Mobile USA has provided us with more granular data on its actual frequency reuse plans in 15 markets. Based upon this more granular analysis of the opportunities for eliminating redundant control channels, we can now confirm that here, too, the gains that will actually be realized through network integration that meet or exceed our and AT&T's previous estimates in the markets we have studied.

Table 3: Opportunities for Elimination of BCCH Carriers

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[8] Because the BCCH is so important, less aggressive frequency reuse is typically applied to this channel than to a voice channel. Thus the BCCH channel can consume a disproportionate amount of spectrum compared to a voice channel.

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As shown in Table 3, in a number of cities the combined company can reclaim **[Begin Highly Confidential Information] [End Highly Confidential Information]** of spectrum that can be repurposed to more efficient UMTS/LTE technologies where it is needed. These are very significant gains in spectrum capacity that can occur only through full network integration.[9]

Utilization/Load Balancing. The merger will also allow the combined company to increase network utilization efficiency. In situations where one carrier's network is relatively

[9] Some critics of the merger note that control channels also carry some voice and data traffic, and complain that AT&T has not shown that this traffic can be accommodated in the combined network if the T-Mobile USA BCCHs are eliminated. We note that most of the non-signaling traffic carried in the BCCH frequency channel time slots is not real-time voice traffic. Furthermore, since GSM uses TDMA, eight time-slots are available and the probability that all eight slots are fully occupied at all times even during a busy hour is extremely low – **[Begin Confidential Information]**

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lightly loaded in a particular area and the other's network is more heavily loaded in that area, combining the networks can yield large utilization or "load balancing" gains that can free up spectrum for more efficient use on UMTS (or LTE) technologies. **[Begin Confidential Information]** **[End Confidential Information]** is a good example of this efficiency; **[Begin Confidential Information]**

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Some have suggested that network utilization improvements cannot occur if both networks are heavily loaded, and speculated that there probably will not be many markets in which one network is lightly loaded and the other is heavily loaded or where both have spare capacity. Substantial load rebalancing can occur even when both local networks are *as a general matter* heavily loaded. This is feasible because load rebalancing from the integration of the two networks can occur *within* geographic areas of markets, not just for the market as a whole.

There can be large traffic variations even within a city (or neighborhood), and often even on relatively heavily loaded networks there could be specific sites or areas in which one network or the other is lightly loaded. This can be due to many factors: the different operators may have customer bases with different demographics (*e.g.*, one operator may have higher proportion of younger customers or of members of a particular ethnic group that drives higher traffic loads in particular areas or at particular times of day); one operator may happen to have more customers in a particular neighborhood than the other; or one operator may have had particular difficulty obtaining good cell site locations in a particular area.[10] Furthermore, one operator's busy hour may occur in the evening, while another operator's busy hour may occur in the afternoon due to the usage patterns of different types of subscribers (*e.g.*, residential vs. business subscribers).[11]

Bringing it All Together – In-Depth Network Integration Studies of Specific Cities. Finally, as we have explained previously, each of the types of spectrum capacity gains we have identified – cell splitting, channel pooling, elimination of duplicate control channels, and network utilization benefits – is independent and cumulative. Although each one of these types of capacity gains can be quite significant alone, the full cumulative impact of all of these gains can be even more substantial. Since our earlier paper, AT&T engineers have performed a complete network integration study of the 49 square mile core area of San Francisco to estimate

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[10] In fact, in Blacksburg, Virginia, Virginia Tech (where one of us teaches) will not allow AT&T to deploy cell sites on the campus!

[11] Imagine 3D maps for each standalone network for a particular city in which both networks are heavily loaded that shows the peak busy hour traffic loads at each cell site as "hills" of various heights. Each operator designs its network so that it will have enough spectrum and radio resources so that target performance levels can be achieved at the sites represented by the *tallest* hills at the busy hour. But if, for the reasons discussed above, the tallest hills for the two operators are not in the same locations, then the combined operator will need fewer radio resources (and less spectrum) than would be implied by simply summing the busy hour traffic at the each operators' tallest hills.

the total GSM spectrum savings from integration. The results confirm our previous expectations: the combined company can operate its GSM network with much less spectrum than the two companies use today as independent operators, freeing up spectrum for redeployment to more spectrally efficient technologies.

The network integration study for San Francisco provides a good illustration of the range of spectrum capacity benefits the merger can provide. In San Francisco, AT&T has experienced rapid traffic growth on its UMTS network. AT&T has a limited amount of spectrum available for its UMTS network, and it is beginning to experience significant spectrum capacity constraints for those services. The merger can provide additional spectrum capacity to handle the rapidly increasing level of UMTS traffic, both by making the UMTS network more efficient (through increased cell density) and by making GSM network more efficient (thus allowing spectrum to be repurposed to UMTS).

We understand that the AT&T engineers performed the same type of in-depth network integration analysis that the combined company would actually perform post-merger. **[Begin Confidential Information]**

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With respect to cell splitting, AT&T, as explained above, examined the specific cell site locations for both networks, using granular traffic and performance data, sophisticated computer models and other engineering tools to determined which T-Mobile USA sites could be productively integrated into the AT&T cell grid to address real world capacity, performance and coverage issues. As noted, in the core area of the city of San Francisco included in the study, this granular analysis led AT&T to conclude that the combined company could keep more than **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** of T-Mobile USA's sites within the area at issue. (In Los Angeles, the same detailed integration analysis concluded that more than **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** of the T-Mobile USA sites can be productively assimilated.) In performing this review, AT&T determined that in some instances, the integrated T-Mobile USA site would provide capacity, service quality *and* coverage gains to the combined company. In addition, the combined company may still decide to keep even more T-Mobile USA sites after the merger, because AT&T has not yet fully analyzed whether other existing T-Mobile USA cell sites have advantages over adjacent AT&T sites (and thus retaining the T-Mobile USA site in the integrated network and decommissioning the adjacent AT&T site could provide additional coverage, capacity and performance gains).

We and AT&T engineers also analyzed, on a granular basis, the expected GSM spectrum savings from the elimination of redundant control channels and from channel pooling and utilization efficiencies. These calculations were based on actual network data, including data on busy hour traffic loads, BCCH allocations, and the number of sectors before and after integration to determine how many channels (and thus how much spectrum) the combined company will need for GSM control channels and for the GSM hopping pool. We and AT&T performed these calculations – and obtained consistent results – using different engineering approaches that reflect sound engineering methods.[12]

These detailed engineering analyses illustrate the impressive gains in GSM spectrum savings. Such savings can be repurposed for UMTS that can be expected from the merger in addition to the direct UMTS capacity gains from increased cell density. In the areas of San Francisco that were studied, we understand that AT&T's GSM network today uses **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** of spectrum and T-Mobile USA's uses **[Begin Highly Confidential Information]** **[End Highly Confidential Information]**, for a total of **[Begin Highly Confidential Information]** **[End Highly Confidential Information]**. Analysis of the total, cumulative achievable spectrum capacity gains from GSM cell splitting, control channel redundancy, and channel pooling efficiencies shows that the combined network will be able to serve the same GSM customer base in that study area with about **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** of spectrum,[13] while keeping the target peak load call blocking and other performance parameters the same.[14] This means, of course, that in the area studied, **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** of spectrum – **[Begin Highly Confidential Information]** **[End Highly Confidential Information]** UMTS carriers – could be shifted to the UMTS network to address current and future capacity constraints.

These significant GSM efficiencies directly benefit the combined company's *UMTS* users, because these gains in spectrum efficiency will free up a large amount of spectrum resources currently used for GSM services to support both companies' customers that can be redeployed to UMTS. Moreover, these capacity gains are in addition to the very substantial UMTS capacity gains that arise directly from the assimilation of T-Mobile USA cell sites into the AT&T grid that substantially increases UMTS cell density and from intercarrier load balancing.

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[12] We describe these approaches and an overall methodology in Appendix A.

[13] *See* Appendix A for the range of gains.

[14] Quantifying the very real network utilization/load balancing efficiencies that can be expected will require even more complex engineering analyses. Our calculations here simply add the busy hour traffic loads of the two standalone networks to determine a combined network busy hour traffic load as if the busy hour peaks of the two networks were located in the same places (geographically and temporally), and they are therefore conservative.

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Appendix A: Methodology for Estimation of GSM Spectrum Savings

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