TEMS™ Capacity Manager: Cost-Efficient Mobile Network Dimensioning

An Ascom Network Testing White Paper

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1 Dimensioning Mobile Communication Networks

Mobile communication networks are very expensive to build and maintain and any cost savings that can be made should be investigated. In order to optimize both the CAPEX and OPEX of these networks while meeting defined Quality of Service (QOS) requirements, mobile operators need to:

- Define network capacity in terms of useful, customer-centric KPIs (blocking and throughput);
- Install capacity for various network elements on a just-in-time basis with sufficient allowance for lead times;
- Exploit "soft" capacity properties of modern mobile network technology.

When dimensioning a network there are two situations that should be avoided:

- Over dimensioning the network—this leads to spending money prematurely;
- Under dimensioning the network—not spending money when there is a need which then results in unsatisfied customers who become more likely to churn.

There is a need for a dimensioning solution to ensure that the mobile networks are neither over nor under dimensioned. However:

- Commercial off the Shelf (COTS) products are limited;
- Radio frequency planning tools are only geared towards green field network planning;
- Network vendor managed services typically dimension the network too conservatively.

TelAri has developed the Mobile Network Capacity Management and Dimensioning tool **TEMS™ Capacity Manager** to monitor a network's performance and assist the mobile network's engineers in ensuring that under and over dimensioning is minimized. This ensures good network performance, and minimizes both CAPEX and OPEX expenditures, while simultaneously satisfying the network customers' quality of service requirements.

In this white paper, we will show how TEMS Capacity Manager can analyse the complex data from mobile communications networks and present the results in a clear and concise form for the operator's benefits. A network wide analysis increases the ability of the operator to target the areas of the network which most need the extra resources; reducing both the amount and delaying the timing of CAPEX upgrades. Individual element analyses ensure that each site can be tuned to its unique environment. TEMS Capacity Manager has already been installed by various clients and over a number of operational years has demonstrated real network operational efficiencies and significant CAPEX savings.

2 The TEMS Capacity Manager Solution

The amount of traffic that can be carried within a mobile communication carrier depends on the radio conditions under which the users' mobile devices operate. A user that has line of sight to a cell' antenna will have a larger capacity than a distant mobile device, partially or fully obscured by structures and/or terrain. In order to communicate successfully with a cell site, customers that operate in good radio conditions do not need as much power as those that operate in bad radio conditions. Each cell's performance is unique because of its particular location, environmental properties and mix of users' traffic. The number of users and the corresponding traffic that can be carried without a significant negative customer impact is specific to this cell. Other resources at the site such as backhaul capacity should be sufficient to ensure there are no traffic bottlenecks. Future expected traffic growth must also be factored in when considering future resource upgrades at a cell site. While traffic forecasts may be network wide the dimensioning of a cell site is unique; it must be evaluated independently of the other cell sites in the network.

TEMS Capacity Manager network dimensioning is achieved by both:

- Macro Level Forecasting – useful for costing and advance purchase of hardware;
- Element Level Trending – useful for determining when a particular network element at a cell site will be unable to meet KPIs and may need upgrading.

The relationship between the different levels of analysis is shown in the graphic below.

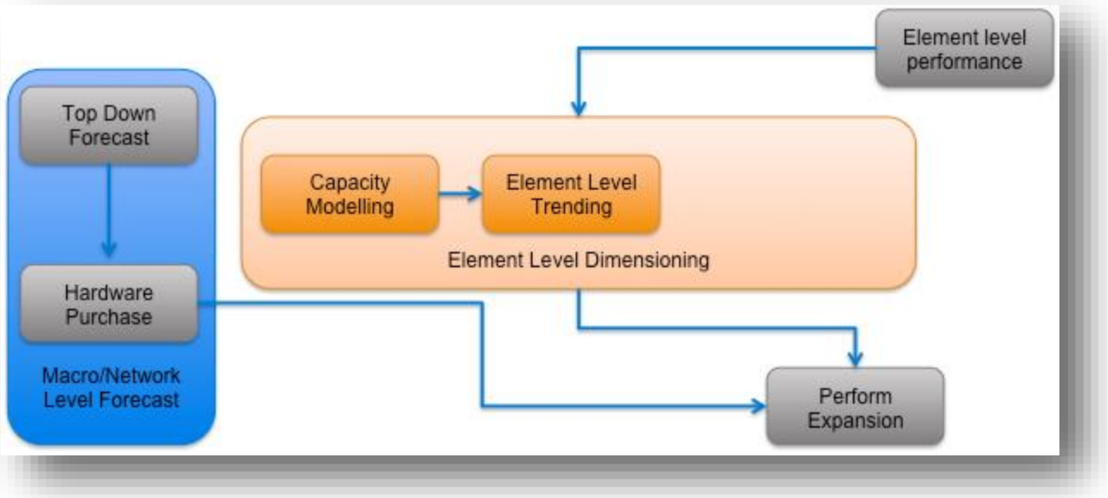

Figure 1: An Example of a Network Dimensioning Process.

TEMS Capacity Manager software has modules for the dimensioning of different resource aggregation levels for each of the following mobile technologies:

1. GSM/GPRS/EDGE
2. WCDMA/UMTS/HSPA
3. LTE

Consequently throughout this paper we refer generically to ***cell sites***, ***nodes*** and ***carriers***, where:

- A cell site refers to a single physical location, for example, all of the mobile network infrastructure co-located at a mobile network tower.
- A node refers to a single baseband unit corresponding to a:
    - BTS/BSC for GSM/GPRS/EDGE
    - Node B for WCDMA/UMTS/HSPA
    - eNode B for LTE
- A carrier refers to a single instance of the combination of node, antenna and carrier frequency, or in long form a “cell-sector-carrier”, noting that an antenna can be omnidirectional, or configured to operate in any one of multiple sectors at a node.

The network elements that are included in the TEMS Capacity Manager dimensioning process are:

1. The air interface - all the resources at a cell-sector-carrier level such as power, frequency and codes needed to carry traffic over the radio channels, as well as any resource that is able to trigger blocking due to Call Admission Control (CAC);
2. Baseband resources at the site – the Tx/Rx boards in existence at each node that are used to implement the physical layer functionality;
3. Backhaul Iub bandwidth – the connection between the nodes at a site and the core. The Iub bandwidth resource may be shared between multiple co-located nodes.

While the air interface is the most complex of these elements, it is important that all of these are considered in the dimensioning process. One under-dimensioned element at a site will cause a bottle neck and hence have an adverse impact on the functioning of this network site.

In the remainder of this whitepaper, unless specifically stated we will refer to the generic ***“carrier”*** rather than one of the above specific network element types, although each could be inferred.

The TEMS Capacity Manager solution monitors a carrier’s configuration and performance counters, models a carrier’s behavior using these data, and assists the network operators in optimally modifying the carrier’s configuration to achieve maximal capacity for a given set of resources. This is done on a carrier by carrier basis using each carrier’s unique characteristics and operational data to ensure that resources are allocated to those carriers that are most in need of upgrading.

The carrier data are also aggregated to give a network wide view. Trends in the network’s traffic can be extrapolated into the future, and used to predict expected network upgrades.

Dimensioning all of the co-located network elements in parallel across all deployed technologies (2G, 3G and 4G) then facilitates sophisticated engineering activities such as load balancing and even spectrum re-farming.

2.1 The Value of User-Centric Analysis

The major purpose of mobile communications networks is to serve the network's customers, ensuring that their service expectations are met. These customer expectations include access to the network, and then good and consistent performance while on the network. TEMS Capacity Manager uses ***User Experience KPIs*** within its analysis to dimension the network to ensure that the users receive the service that they expect.

It is possible in a modern (post-2G) mobile communications system to keep adding additional users for quite some time without causing hard blocking (due to CAC). This ability to cope with additional demand, is known as "soft capacity" and is one of the reasons that some WCDMA and LTE carriers are capable of supporting substantially more carried traffic (while maintaining a similar user experience) than other carriers. However, as additional users are added, interference increases and the overall user experience decreases. The degradation of user experience is a function of User Equipment (UE) distribution within a carrier, external interference and other environmental parameters. This means that if *typical* carrier capacity is used to dimension the entire network to a given set of KPIs (rather than estimating soft capacity on a carrier by carrier basis), then high capacity carriers will be expanded well before they should be, and low capacity carriers will not be noticed until they have significantly violated their KPIs, leading to dissatisfied users and risking higher customer churn. The detailed traffic modelling performed by TEMS Capacity Manager specifically lends itself to dimensioning to ***User Experience KPIs*** in addition to ***Engineering KPIs***. These by necessity must consider the combined utilization of different network resources and the effect that this has on session quality. The different sessions may be a combination of services, such as voice or video that needs different KPIs. These service KPIs are important when determining the carriers' capacities. Dimensioning to User Experience KPIs also makes it easier to provide a consistent user experience across a wide range of hardware configurations (especially when the effects of soft capacity are considered).

Examples of Engineering versus User Experience KPIs are shown in Table 1.

Resource	Engineering KPI Trigger		User Experience KPI Trigger
DL Power	Utilization (%)		Average HSDPA User Throughput (Mbps)
UL Power	Load Factor (% of pole capacity)		Average HSUPA User Throughput (Mbps)
UL CEs	Utilization (%)		Blocking (%) and Average HSUPA User Throughput (Mbps)

Table 1: A Comparison of Engineering and User-Experience KPIs.

2.2 Key Information for Network Operators

The major TEMS Capacity Manager capability is that the complete capacity state of the network is efficiently reported to the network operator, and predictions on capacity limitations and remediation are made, tailored to each network element. The resource utilization for every carrier in a mobile network is represented using a single value metric called ***Headroom***. When Headroom is positive the dimensioned network element has spare capacity, when negative, the network element is not meeting one or more of its User Experience KPIs. Single carrier and network wide Headroom reports show the operator a snapshot of the network and where potential dimensioning issues may be arising.

TEMS Capacity Manager uses an analysis engine which:

- Incorporates the specific call admission control (CAC) rules implemented in the vendor equipment;
- Captures statistics related to admission control *(Blocking);*
- Captures statistics related to key performance indicators *(Throughput).*

TEMS Capacity Manager uses this information to:

- Generate the set of data points in service load space for which KPIs are met, known as the ***Admission Region (AR)***;
- Calculate spare carrier capacity;
- Forecast traffic growth at a site;
- Calculate a ***Time to Expansion (TTE)*** based on trending spare carrier capacity and forecasted traffic growth;
- Calculate a carrier's limiting resource(s) now and into the future;
- Determine when the User Experience KPIs will be breached.

TEMS Capacity Manager performs a number of tasks on a carrier by carrier basis. These include:

- Read carrier's configuration parameters;
- Read carrier's current traffic profile;
- Calculate a set of environmental parameters that characterise the carrier's radio environment;
- Use simulation to determine the carrier's Admission Regions, described below;
- Perform forecasting routines to determine when a carrier with spare capacity will have that capacity exhausted;
- Predict the set of resources that are, or will be, limiting capacity;
- Enter data to database;
- Present data in easy to use charts, tables, and maps in a web based client.

2.3 The Reference Period

In legacy communications networks, especially circuit switched networks, dimensioning was a relatively simple matter of using some characterization of “busy load” as input to the Erlang-B formula for a given target KPI (e.g. blocking probability). Most operators chose to use Time Consistent Busy Hour (TCBH) as reference for deriving the busy load. It was defined to be the one hour in the week that most often recorded the highest load (or some operator specified percentile of the highest load).

In modern mobile networks, with multiple services co-existing and each placing quite varied “load” on the network, it is not a simple matter to derive a reference mechanism analogous to TCBH.

TEMS Capacity Manager allows a network operator to specify their own reference mechanism for characterizing “busy load”, due to the fact that the aggregated load of all offered services has been used in deriving a single performance statistic, namely Headroom. This metric can be calculated as often as is needed (the default is hourly), and then the distribution of Headroom values across any given analysis period can then be assessed to obtain a ***Reference Period***.

It is too expensive to dimension a network to be able to cope with the busiest of periods, so the default Reference Period for TEMS Capacity Manager is defined as all periods with headroom values lying between the 89^{th} and 91^{st} percentiles. This also allows a single “banner number” to be produced for each dimensioned network element – the 90^{th} percentile of headroom is used to reflect the capacity of a given network element for the period under consideration. These percentiles can be changed by the network operator. The Reference Period then becomes another key output of TEMS Capacity Manager. Any other performance metric of interest can be filtered using the reference period to provide the network operator with a consistent view of network performance, analogous to tracking TCBH load.

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3 Types of Analysis for Network Operators

TEMS Capacity Manager analyses a network on a carrier by carrier basis. Each carrier has its own characteristics and hence capacity. The software looks at these characteristics, calculates the amount of traffic that can be carried on these carriers, and presents the results as the carrier's ***Admission Region***. Furthermore a measure of how far this specific carrier's current load is from the limit of this carrier's carrying capacity is calculated, the carrier's banner ***Headroom*** (median ***Reference Period*** value). These calculations are carried out for every carrier in the network and are presented in a network wide report. The number of at risk carriers can be displayed, and a drill-down feature enables the network operator to investigate the specific carrier that may be under dimensioned. A comprehensive carrier analysis then helps the operator determine what the carrier's limiting resource is. Below we look through some examples of the TEMS Capacity Manager outputs and demonstrate some problems of interest.

3.1 Carrier-Level Analysis

The fundamental analysis tool of TEMS Capacity Manager is a carrier simulation engine using the carrier's unique data. This engine simulates the carrier not only using the carrier's current load and parameter configuration but other configurations. This enables the analysis engine to predict how the carrier will react to traffic growth. And it is this capability which in turn powers the network wide analysis.

There are many carrier parameters that help define that carrier's capacity and other characteristics. These include:

- The configuration of that carrier, such as the amount of frequency and power of the carrier's transmissions;
- The Call Admission Control set up, which defines how many and what types of calls may be admitted to a carrier;
- Environmental parameters characterizing the radio environment. For example the percentage of handsets that are EUL capable, or the amount of downlink power consumed may both depend on the carrier's location, user numbers and behavior;
- The KPIs for the different services that are being offered on this carrier.

TEMS Capacity Manager' determines all of these data on a carrier by carrier basis from a data base a data base that has been populated by and derived from data *read from the network carriers*. The *carriers*. The table in

Figure 2 shows a lot of a carrier's parameterization based on an Ericsson WCDMA vendor implementation. Graphical representations of these data can be displayed. For example in Figure 3 we can see the historical traffic data at a carrier.

Parameters	
Vendor:	Ericsson
Week Starting:	16/07/2012
NSD Cell Type	
Power:	Metro (3W)
Capacity:	(Unknown)

Environmental		
Speech using AMR12.2	100	%
EUL Load Factor per User	0.020	LF/Mbps
HS Codes per User	0.1	SF16
HSPA using EUL	77	%
HS Power per User	0.3	W
Load Factor per User	0.280	LF/Mbps
R99 Power per User	84.3	mW / kbps
R99 PS Activity Factor	14	%
SHO Overhead	22	%
SRB using 13.6	100	%
Total CCH Power	39.0	dBm

Configuration		
RAN Version	W11b	
aseDlAdm	240	ASE
aseUlAdm	300	ASE
R99 CCH Codes	5	SF128
dlCodeAdm	90	%
eulMaxOwnUuLoad	8	dB
eulNonServingCellUsersAdm	100	
eulServingCellUsersAdm	32	
hsdpaUsersAdm	90	
hsPowerMargin	0.2	dB
maxTransmissionPower	45.4	dBm
maxNumHsdpaUsers	96	
maxNumHsPdschCodes	15	SF16
numEagchCodes	1	SF256
numEhichErgchCodes	1	SF128
numHsPdschCodes	1	SF16
numHsScchCodes	3	SF128
primaryCpichPower	35.0	dBm
pwrAdm	90	%
sf16Adm	8	
sf16AdmUl	50	
sf16gAdm	8	
sf32Adm	16	
sf4AdmUl	2	
sf8Adm	4	
sf8AdmUl	8	
sf8gAdmUl	8	

Figure 2: A WCDMA Carrier's Configuration and Environmental Parameters.

Using these data, simulations are run for different traffic combinations which indicate what can and cannot be carried by the carrier without breaking user experience KPIs. The ***Admission Region*** for a specific carrier indicates the amount of different types of traffic that this carrier can carry—all the possible combinations of the services that can be carried by the carrier without violating any of the carrier's KPIs. For example, there are 5 broad categories of services that may be offered in a WCDMA carrier:

1. Video – a guaranteed rate service;
2. Speech – a guaranteed rate service;
3. SRB – Signaling Radio Bearer – used for signaling and administrative data;
4. R99 Packet – Release 99 data access – max rate 384 kbps, and;
5. HSPA – High Speed Packet data Access – a high speed downlink bearer may be supported using either an R99 Packet uplink, or an Enhanced Uplink (EUL).

Each of these services has different characteristics and hence requirements and costs associated with them. Also each service has its own associated KPIs – for example, latency is a vital consideration for voice traffic, but not as important for data streaming. A carrier can carry a limited amount of these services and a limited mix of these services, while adhering to the different KPI requirements. The admission region is an indication of how many concurrent instances of these services can be carried by a carrier given its current configuration.

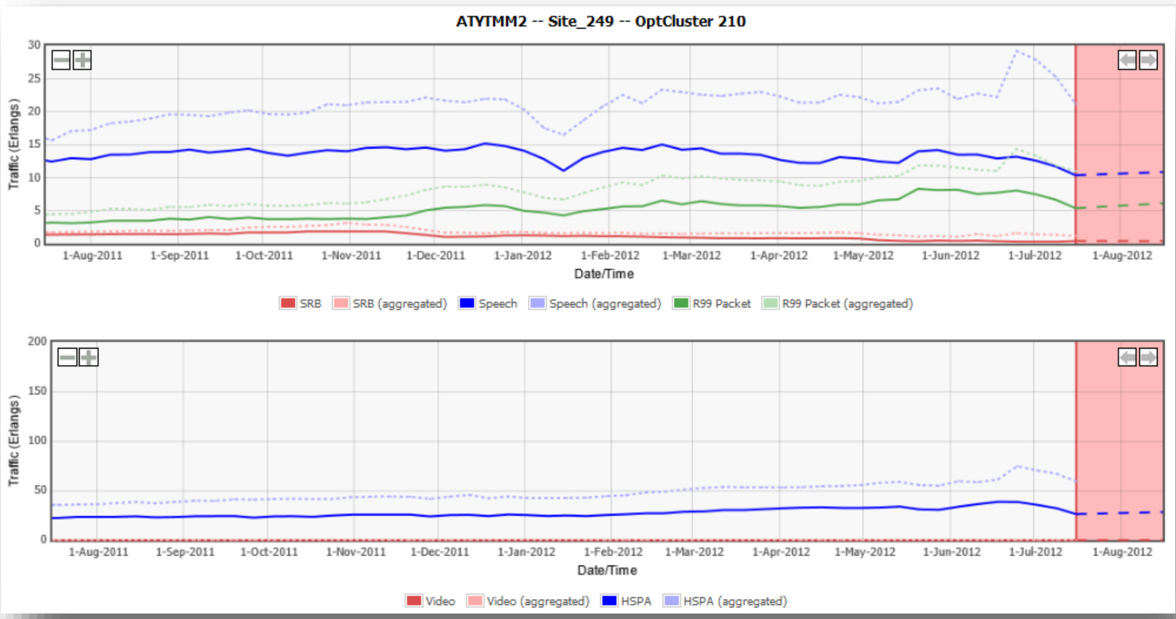


Figure 3: The Traffic at a Carrier by Service.

Since there are five broad categories of service it is not possible to portray this space on a single graph. Instead any combination of two of the services can be displayed together. So for example in **Figure 4** below the admission region of HSPA and speech traffic is presented. This is indicative of how much each of these services can be carried on the carrier together, although care must be taken in interpreting these results since this is a two dimensional representation of the five dimensional admission region. In this example without violating the carrier's KPIs this carrier cannot carry more that about 30 Erlangs of HSPA traffic, nor more than 22.5 Erlangs of Speech traffic, nor more than 20 Erlangs of HSPA and 15 Erlangs of Speech traffic.
Also on the admission region graph are the traffic points for this carrier's recent history. A specific week's points can be highlighted. And another set of traffic points, the traffic measured during the hours that make up the Reference Period, has been highlighted in red. In this example the reference traffic points are busier than 90% of all measured traffics. These have been chosen to get a good measure of how busy the carrier is. The busiest 10% of points have been excluded as they may be due to unusual activity or radio environment. The graph indicates how close the reference traffic is to the admission region boundary. This distance is called the Headroom of the carrier and is the main parameter that is calculated and reported on a carrier by carrier basis. A large positive Headroom indicates that the carrier is lightly loaded; a low positive Headroom indicates that the carrier is heavily loaded and further investigation may be necessary to determine whether upgrades to the carrier are necessary. A negative Headroom indicates that the carrier's subscriber based KPIs are most likely being violated and measures must be taken to upgrade the carrier. For example the carrier in **Figure 4** is moderately loaded and the banner Headroom is 43%.

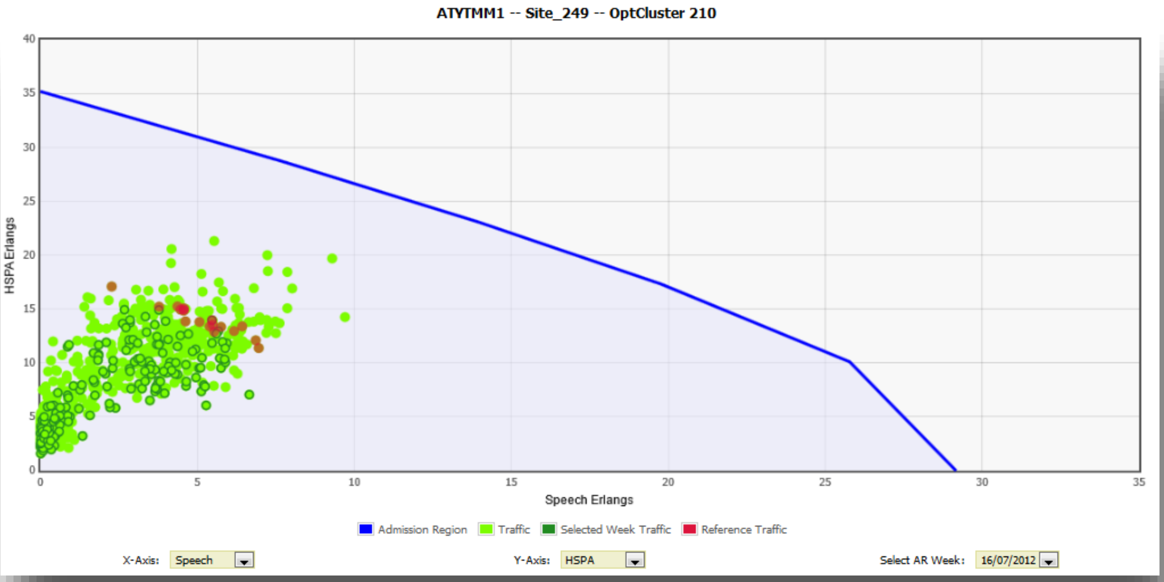


Figure 4: A Carrier's Admission region with a Headroom of 43%.

The carrier in Figure 5, however, has its traffic points close to the admission region. In this case the Headroom is -10% and further investigation is necessary to determine what resource is limited.

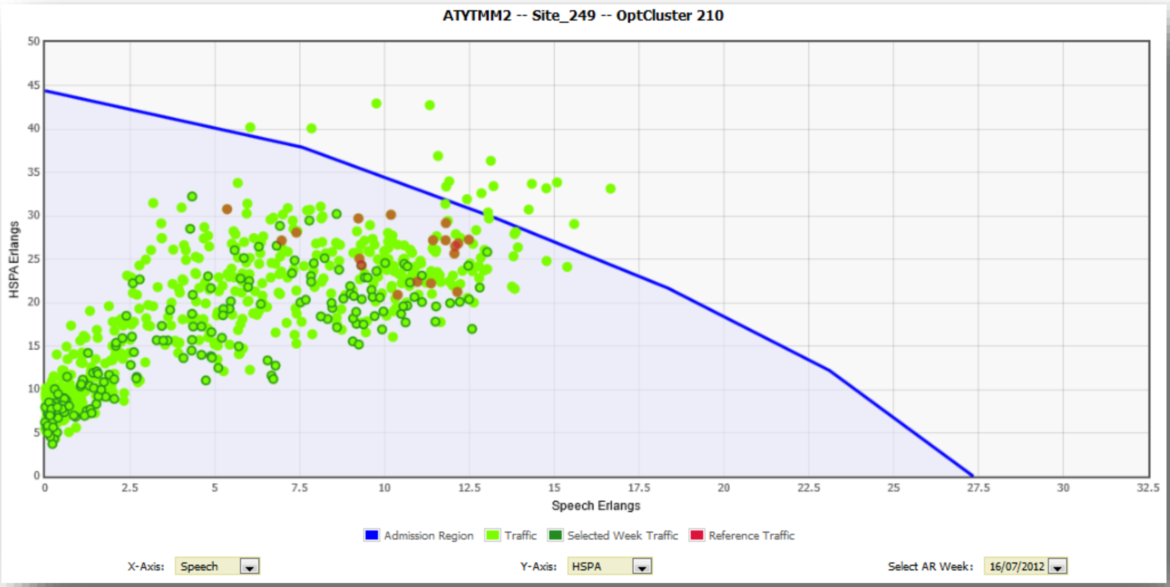


Figure 5: A Carrier's Admission region with a Headroom of -10%.

For any carrier we can inspect the impacts on services and the limiting resources, as shown in **Figure 6**. This graphic shows data for the carrier in Figure 5 broken down into services and resources. We can see that it is the HSPA service which is impacted and the reason for this is that the downlink (DL) power is a limiting factor. These results direct the operator to the ways in which this carrier's performance can be improved. In this case look at increasing the downlink power – for example a higher powered antenna, or carrier sectorization.

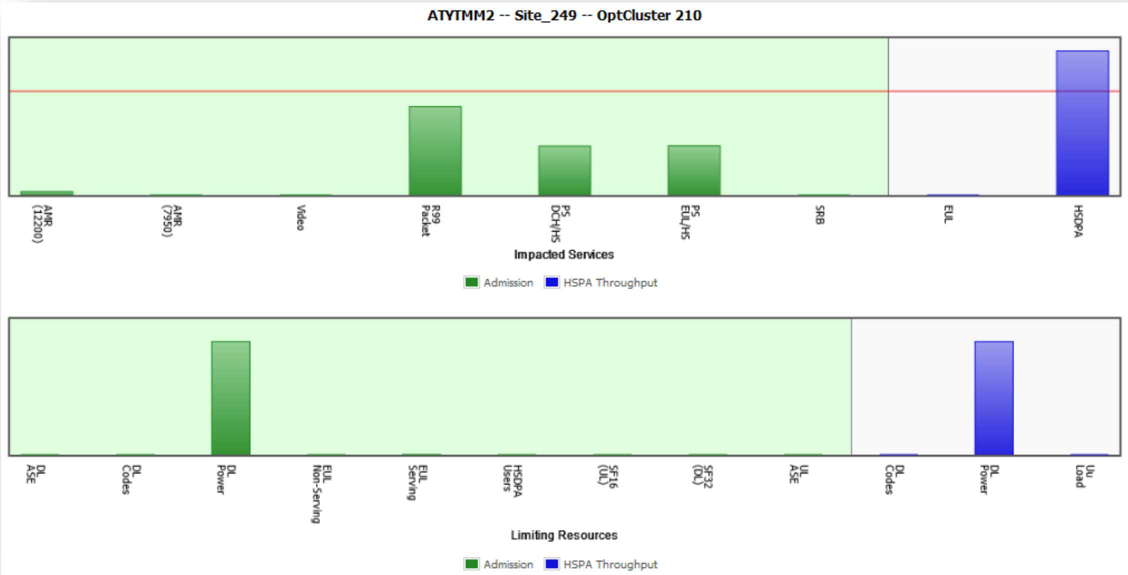


Figure 6: Display of impacted services and limiting resources for one carrier.

3.2 Carriers Exceeding Capacity

A suitable next step for a capacity engineer would then be to see which network elements are exceeding their capacity at a particular site. The graphics below show for a particular site the Headrooms for each of the dimensioned network elements, namely the Node B baseband and Iub bandwidth (for two Nodes B – see the top section of the chart) and the carriers on a sector by sector basis. Note that there are three frequency bands in operation in each of this cell site's sectors. This chart also indicates whether the carriers within a particular sector are balanced or not. Unbalanced sectors can have their capacity issues improved by rebalancing load between the different frequencies. Finally, by extrapolating traffic data and rerunning the analysis engine an ***Expansion Date*** is also predicted indicating when these network elements are expected to need an upgrade if the targeted levels of subscriber experience are to be maintained. The ***Time to Expansion (TTE)*** is calculated based on the Expansion Date.

NodeB Overview:

Cabinet #	RBS	Headroom	# Cells	Expansion Date
1	ATYT (330001994)	35%	6	22-09-2012
2	ATYT (330002721)	70%	3	03-01-2014

Sector	Cabinet #	Cell	Headroom	Headroom Balance	Carrier	Expansion Date
1						
	1	ATYTLM1	72%	Balanced	LM	-/-/-
	1	ATYTMM1	43%	Balanced	MM	13-03-2013
	2	ATYTNM1	61%	Balanced	NM	26-05-2014
2						
	1	ATYTLM2	26%	Unbalanced	LM	01-09-2012
	1	ATYTMM2	-10%	Unbalanced	MM	16-07-2012
	2	ATYTNM2	46%	Unbalanced	NM	06-06-2013
3						
	1	ATYTLM3	76%	Unbalanced	LM	-/-/-
	1	ATYTMM3	30%	Unbalanced	MM	07-08-2012
	2	ATYTNM3	54%	Unbalanced	NM	13-12-2013

Figure 7: The Headrooms for all the network elements at a specific site.

3.3 Carriers Operating Beyond Network Capacity

Once the carrier by carrier analysis has been performed, we can then see an overview of the whole network. The graphic below shows the historic plot of the general health of the network, indicating how many carriers are operating beyond capacity. This network is fairly stable with less than 5% of nodes operating beyond capacity over the two year period. When the number of carriers trends upward towards the 5% level, it can be seen that remedial dimensioning has taken place and the percentage reduced. This shows that the network has been managed efficiently with neither too many nor too few carriers going beyond their capacity targets. This is indicative of efficient use of CAPEX.

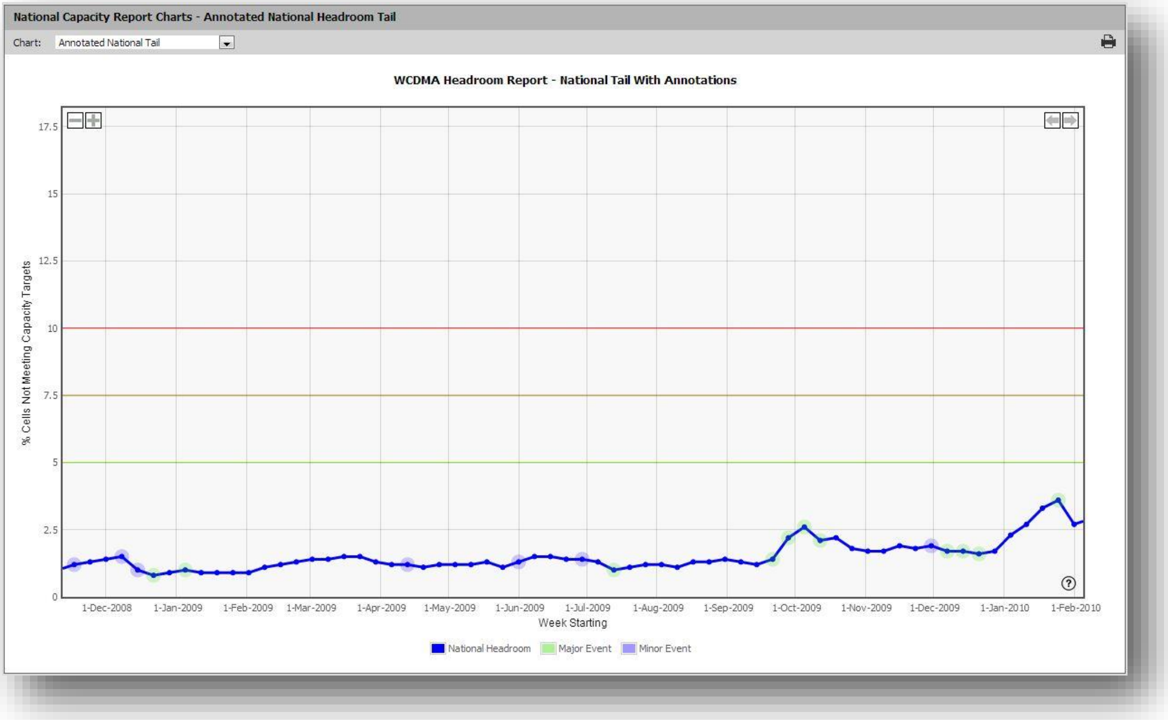


Figure 8: A high level plot indicating how many carriers are operating beyond capacity.

A list of the worst sites in the network can also be shown. Figure 9 shows an example list. When using the software clicking on any particular site's name will take the user to the analysis of that site where further information on that site is available. This enables the network operator to quickly tackle the most critical carriers in the network that need to be investigated to improve the network's performance.

State	Opt. Cluster	Site LRD	Site Name	Iub Id	Worst
STA_8	OptCluster_186	BNWD	Site_1087	330000329	-212%
STA_8	OptCluster_194	WMVD	Site_7334	330001098	-177%
STA_8	OptCluster_165	WBUD	Site_4461	330000796	-174%
STA_8	OptCluster_194	PCKX	Site_5381	330001813	-149%
STA_8	OptCluster_194	WYVF	Site_7335	330002000	-149%
STA_8	OptCluster_182	FRJD	Site_2479	330001573	-147%
STA_8	OptCluster_196	BGBD	Site_639	330002151	-145%
STA_8	OptCluster_201	FCCD	Site_2356	330000501	-142%

Figure 9: A list of the sites whose carriers have the worst Headrooms.

3.4 Planning a Capacity Expansion – Experimental Analysis

Underpinning TEMS Capacity Manager is a set of customized models, one for each distinct network element. These models are updated whenever the banner Headrooms are re-calculated (we suggest every week for WCDMA and every hour for LTE). The models can then be reused to undertake any type of "what-if" experiment to determine how configuration changes, or different traffic loads will impact performance. A RAN engineer can use this experimentation capability to determine how best to remediate a capacity problem. TEMS Capacity Manager will identify the constraining resource(s) and then allow the engineer to re-run the analysis as if their chosen capacity expansion had already been implemented.

For example, experimentation on individual network elements can be performed to plan for special events.

Moreover, a single experiment can be run with just a few clicks to evaluate the impact of a site-wide, region-wide or even network-wide change. Examples of experiments that run on multiple network elements simultaneously are:

- Determine the impact on network health of a doubling in traffic at every carrier.
- Determine the impact of upgrading baseband to a newer release at every carrier in a given RNC.

The example in Figure 10 is for a WCDMA carrier that was capacity constrained by a lack of downlink power. By simply changing maxTransmissionPower (a key input parameter) from 46dBm to 47dBm in a "what-if" analysis we can see that the carrier would improve from a banner Headroom of -25% to +7% as the admission region boundary expands. Any combination of configuration changes, environmental changes, KPI changes and traffic changes can be made in each experiment.

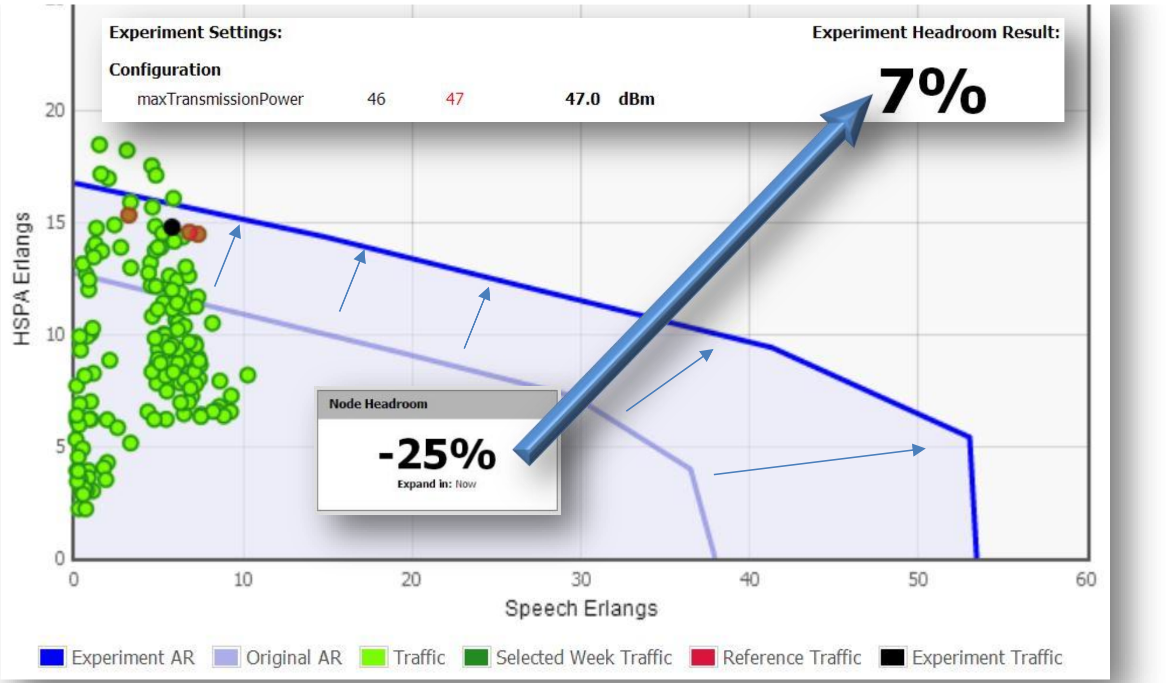


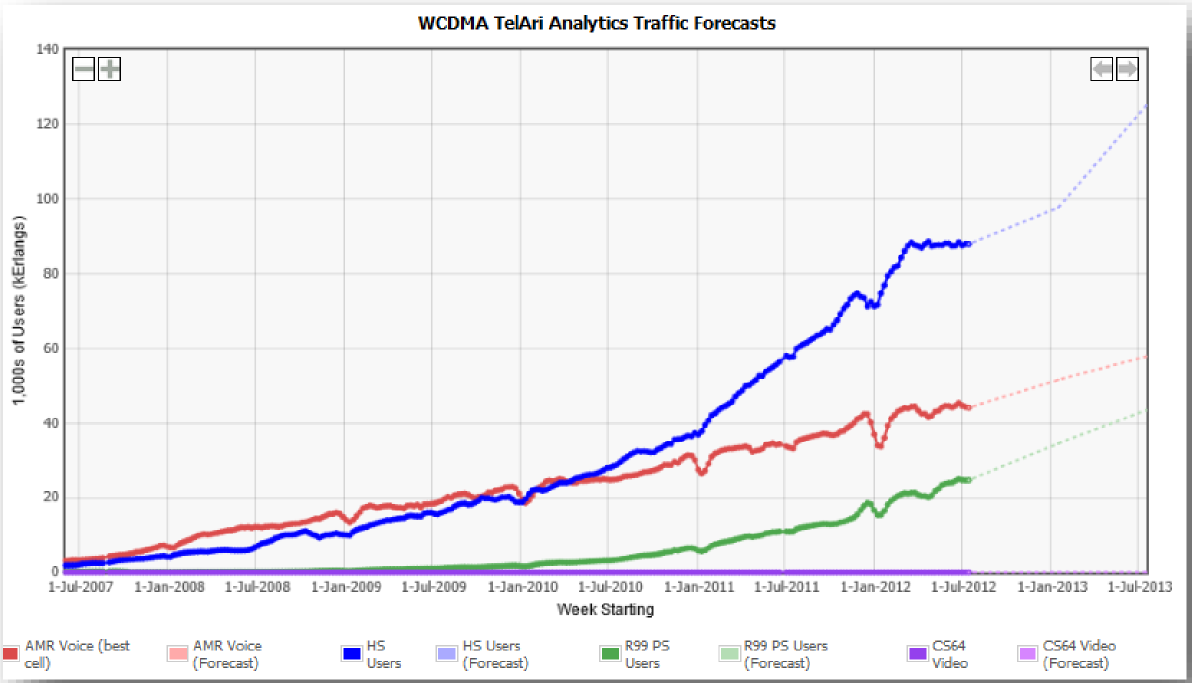
Figure 10: "What-If" Analysis Investigating an Increase in Transmission Power.

4 Forecasting Network Capacity Problems

TEMS Capacity Manager combines both top-down forecasting and bottom-up forecasting to perform element level trending. The historical aggregated traffic for the network can be plotted and recursion techniques applied to extrapolate the traffic into the future – see **Error! Reference source not found.**. This top down analysis leads to approximate growth figures for the network. These growth figures can then be applied to the individual carriers to estimate their traffic growth, and hence expected future behavior.

This process forecasts traffic growth at a carrier to estimate a date when capacity will be exhausted. Having an accurate idea of when capacity will run out (the date at which Headroom is predicted to reach 0%) allows capacity expansion project lead times to be better managed.

Figure 12 (next page) shows traffic growth for a selected carrier, with a forecast showing when 0% Headroom will be reached. In this case the Headroom is 72%, and it is forecast that with the growth in carrier traffic the Headroom will be 0% in about 22 months' time (note that this analysis took place on June 2012.) This analysis is performed for all of the carriers in the network and the aggregated results give an



indication of expected future CAPEX to keep the network efficiently dimensioned.

Figure 11: Historical and Predicted Traffic.

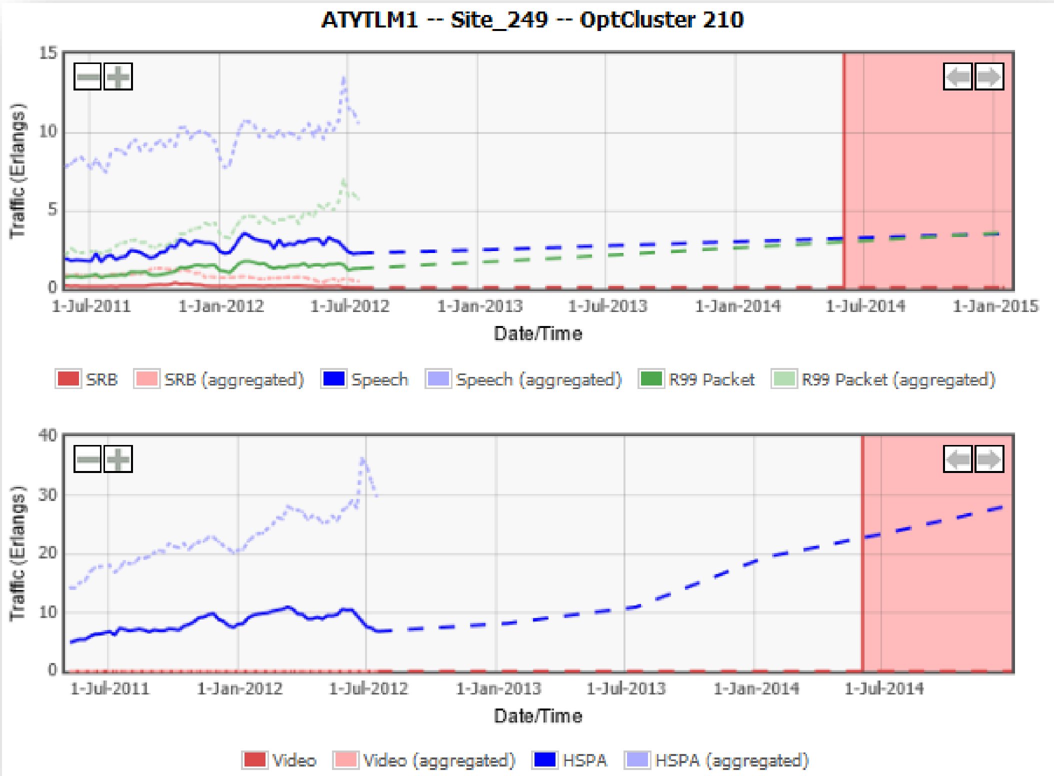
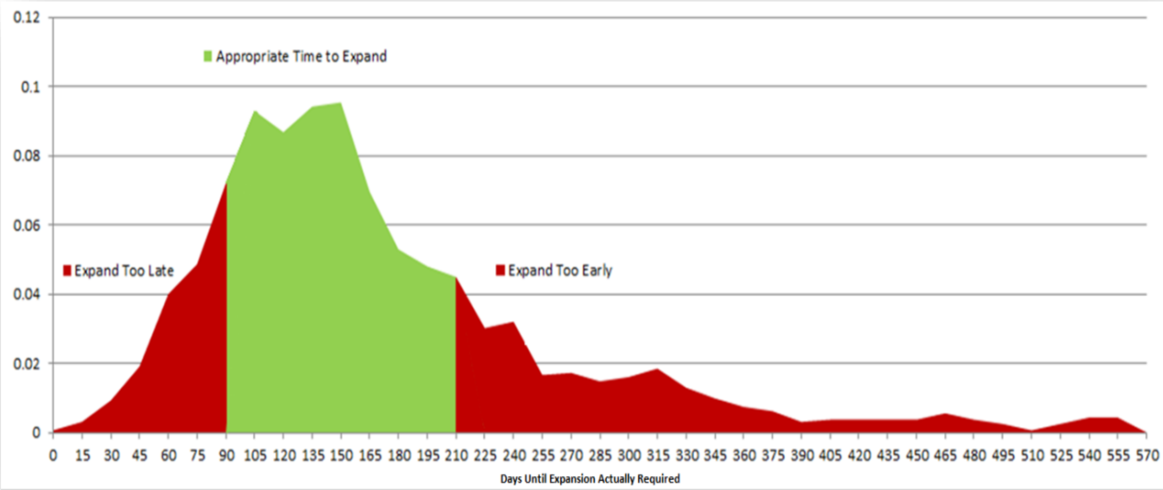


Figure 12: Carrier level traffic growth, showing when 0% Headroom will be reached (red shaded region).

When this carrier by carrier analysis is performed on a network a future planning strategy can be devised and implemented. The graph in Figure 13 demonstrates how TEMS Capacity Manager helps perform this strategic planning. Suppose that we expect that the lead time between briefing a capacity expansion and it actually occurring is approximately 5 months, assume a suitable time is between 3 and 7 months. All the carriers in this network have been analyzed and the expected time of their Expansion Dates calculated. Each carrier will then fall into one of three categories. These are:

- Expansion date is less than 3 months. Unless already scheduled, expansion is too late to avoid subscriber experience degradation; for these carriers a capacity expansion must take place after the carrier's expected Headroom has gone below 0%;
- Expansion date is between 3 and 7 months. Scheduling the carrier's expansion now should ensure that the carrier is not under dimensioned;
- Expansion date is greater than 7 months. Scheduling these carriers for expansion now would be premature. Their Headroom is expected to be positive looking beyond the 7 month horizon.

Given these three carrier categories we can deduce that for this network about 30% of carriers are in the first risky category and so must be immediately investigated if expansion has not already been scheduled. Customers served by these carriers are expected to suffer unacceptable performance for at least 2 months with the actual cost of unhappy customers (possible churn) hard to quantify for the network's owners. About 40% of carriers are in the second category. Plans for their expansion should be scheduled about now and if expansion takes place as scheduled customers in these carriers will remain satisfied with the network's performance. Another 30% of carriers are in the last category. Expansion should not be scheduled yet. Some of these nodes



may have been prematurely expanded representing inefficient expenditure of CAPEX.

Figure 13: Distribution of days until the network carriers needs to be expanded.

Expressed another way, dimensioning this network to the average carrier configuration and radio environment would result in at least 30% of carriers being provided a capacity expansion too early (wasting CAPEX) and 30% too late (risking customer churn). Use of TEMS Capacity Manager would make CAPEX at least 30% more efficient, and also reduce OPEX due to the improved visibility into specific carrier capacity issues from the custom modelling per network element.

This analysis should periodically be updated so that the actual dynamic network traffic and conditions can be included in the analysis. Continuous monitoring of the network will ensure that the network is correctly dimensioned and the network's customers will remain happy with the offered services. An example of the expected Time to Expansion (TTE) for a particular carrier is shown in Figure 14. Here the TTE has changed over time as the carrier's radio environment and underlying configuration have changed. For example it is clear that a capacity expansion (configuration change) took place in October 2011, and another one will be needed soon (based on "now" being December 2012).

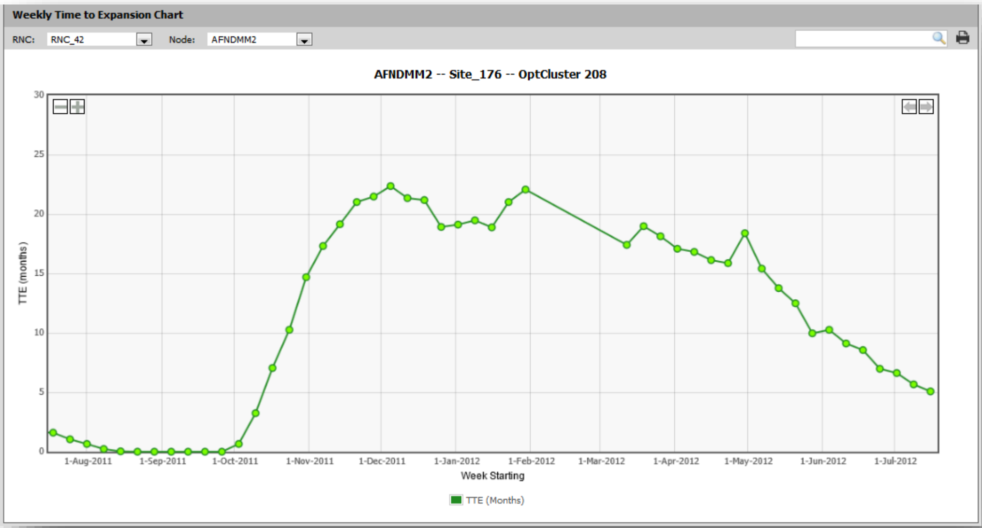


Figure 14: Changing Time to Expansion for a carrier.

Accurately classifying expansions based on element level trending, therefore, makes CAPEX expenditure much more efficient, but it also improves OPEX, as radio network engineers are provided with a prioritized list of nodes needing their attention. They remain informed at all times as to where to expend effort. The automated root-cause analysis capability also drastically reduces the time required to prepare a capacity expansion briefing.

5 HetNets, Small Cells and Spectrum Re-Farming

TEMS Capacity Manager customers rely on the tool to dimension their macro layer cellular networks. At some point their most critical resource (spectrum) will become exhausted and from then on there is no clever dimensioning technique that can resolve capacity issues – unless there is offload to a small cell or HetNet (micro) layer. In Figure 15, comparing TEMS Capacity Manager element level trending (in blue) with spectrum (capacity) availability (in red) allows for a micro layer strategy to be evolved "just in time" and assists in devising spectrum re-farming strategies that can maintain targeted user experience.

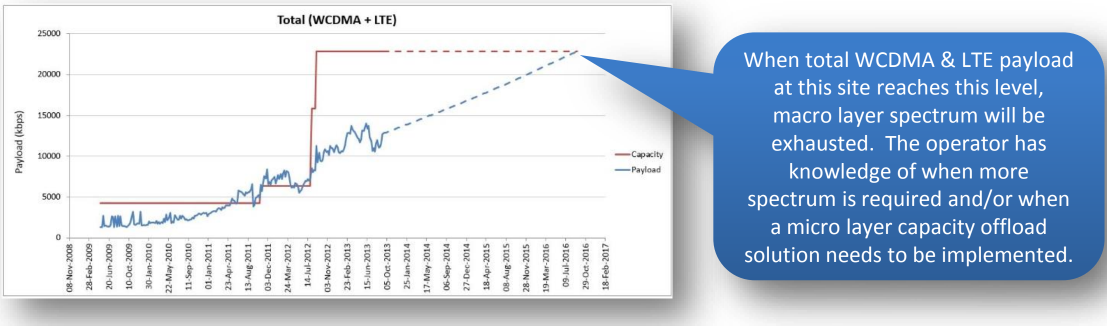


Figure 15: Identifying the Need for Small Carriers and Hetnets, or Spectrum Re-farming Strategies.

6 The Benefits to Network Operators

By now you should have an appreciation of the difficulty that network operators have in making decisions on network dimensioning, and how TEMS Capacity Manager can assist in guiding operators in making these important decisions. Ultimately, if User Experience KPIs are used to guide the growth of networks, we think there are significant financial advantages for network operators, and our clients agree: TEMS Capacity Manager is a critically important part of this process.