White Paper

The Essential Importance of LTE TDD for Small Cell Deployments

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Executive Summary

- The rate of adoption of smartphones and new mobile devices such as tablets are driving the use of mobile data often described as “the Data Tsunami”.
- Meanwhile, operators face spectrum shortages and new spectrum is very highly priced.
- The only feasible way for mobile operators to cope is by increasing the densification of the networks via small cells.
- As a result, the small cell market is expected to expand dramatically in terms of unit shipments and revenue during the next few years.
- The driver for traffic is data traffic, particularly video data, which (unlike voice) is highly asymmetric.
- Historically, TDD has not been mainstream or widely considered for cellular. However, LTE TDD offers the potential of solving many problems for carriers.
- In particular, LTE TDD is well suited to:
  - Matching the inherent asymmetry of the traffic.
  - Increasing the overall capacity of the system, especially in the small cell case.
  - Making best use of spectrum and otherwise wasted bands.
- Combining traditional FDD with an optimized TDD small cell layer could increase the overall spectral efficiency by 38% and increase downlink capacity by 77%. This would result in reducing TCO (Total Cost of Ownership) by 44% for the same DL capacity compared to a legacy FDD only deployment.
- In addition, small cell TDD is inherently more power efficient, increasing UE battery life by >50%.
- Finally, operators will have access to more spectrum, and often at more attractive prices, further improving the economics.
- It is therefore not surprising that analysts such as Mobile Experts predict that by 2017 there will be approximately 23 million LTE TDD small cells in the market, approximately one-third of the total small cell deployment and growing at a rate 3x faster than FDD small cells.
- Industry and regulators should therefore move away from the legacy mindset of voice services and FDD only, and instead adopt a new paradigm based on optimal combination of FDD and small cell TDD to better match the traffic asymmetry of data services and take full advantage of spectrum availability.
TDD and Small Cells – Technological Kismet

TIME TO THINK AGAIN ABOUT DUPLEXING

Since its inception, the cellular industry has adopted Frequency Division Duplex as the basis of virtually every mainstream technology standard, from TACS and AMPS through GSM, cdma2000, WCDMA and now LTE. For networks architected to maximize coverage for voice-centric services (with an inherently symmetric traffic mix), FDD formed a natural and logical choice – supporting large cell sizes and simplifying early handset designs.

We are living in a period of disruptive change as great as any the industry has ever seen. The rapid growth of data consumption driven by the tremendous success of the smartphone and tablet (see The Data Tsunami) is forcing nothing less than a revolution in our approach to network design and deployment.

Meanwhile, spectrum usage has become critical. Given the scarcity of new bands and the high value ($/MHz/POP) of spectrum as an asset, it is essential that carriers make the best use of spectrum they currently possess before regulators can be persuaded to transition other bands.

The Data Tsunami

The future of the Internet is mobile and wireless. Since the introduction of the iPhone and the adoption of 3.5G HSPA technology in the networks five years ago, we have witnessed a huge change in consumer behavior - away from broadband internet access as essentially a static wireline-based activity towards fully embracing smartphones, tablets and netbooks as primary tools for social networking, entertainment and the enterprise.

For the mobile network operators this trend has occurred at breakneck pace and the scale of demand threatens to overwhelm the capabilities of existing and planned deployments to deliver acceptable user experience. Industry projections foresee demand, driven especially by mobile video consumption, only accelerating into the later years of this decade.
It is only fitting, in the midst of such change, that we should revisit our deeply held assumptions about all aspects of cellular network design – duplexing modes included.

This White Paper makes the case for Time Division Duplex to be considered not simply as a regional or band-specific solution to spectrum access, but as a fully-fledged, mature technology which deserves to be considered as the primary mainstream technology for LTE small cells. It discusses the technological aspects of LTE TDD and why it is such a good fit for a small cell deployment, as well as market trends and some myths about TDD.

Small Cell Market

According to Cooper’s Law [3], the theoretical capacity of wireless communication has doubled every two-and-a-half years for the past 104 years. An analysis of the last 45 years of the capacity gain brought by technology improvements, increase of spectrum and reduction of cell size shows that the vast majority of the gain comes from the spectrum reuse that a smaller cell size enables.

It is clear that the deployment of small cells will be an essential part of the solution to The Data Tsunami. But what is perhaps less appreciated is how LTE TDD small cells can further dramatically improve on this potential.

The vast majority of network operators planning commercial deployments of LTE technology agree that small cells will play an important role in their plans. Informa Telecoms & Media [4] shows that 98% of mobile operator respondents believe that small cells are key for the future of mobile networks. The reasons are not hard to find: faced with a limited supply of available spectrum on the one hand, and the unforgiving physical laws of Maxwell and Shannon on the other, there is simply no other practical way to increase network capacity for dense user populations than to reduce cell size.
SMALL CELLS AND TDD - THE NEW ORTHODOXY

The challenge of the service provider is now dominated by ensuring sufficient capacity to meet user expectations for latency and throughput, not simply connectivity.

In this context, old assumptions underlying basic technology decisions break down. While FDD has a longer pedigree in cellular, and is inherently matched to symmetric traffic, it is no longer the only approach. In the case of duplex techniques, TDD has been adopted with success for short-range technologies. Its many advantages (see FDD and TDD – The Pros and Cons) become significant factors in optimizing small cell network performance, while the disadvantages can be seen to be either no longer relevant, or at least manageable with current technology in a small cell context.

Driven by the scale of the pioneering TDD markets, and by the appeal of TDD as a global roaming solution, handset and device support is assured.
<table>
<thead>
<tr>
<th>Feature</th>
<th>FDD</th>
<th>TDD</th>
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<tbody>
<tr>
<td><strong>Flexible Assignment for Data Asymmetry</strong></td>
<td>FDD assigns fixed spectrum allocations for both uplink and downlink</td>
<td>A number of configurations exist to support both symmetric and asymmetric traffic (see Asymmetry – the TDD Trump Card)</td>
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<td><strong>Globally Available Roaming Spectrum</strong></td>
<td>The lack of global agreements on spectrum allocation for LTE FDD represents a serious challenge to true international roaming</td>
<td>A number of bands have been agreed internationally. More than 50% of the world’s population will be covered by TDD networks in the 2.3 – 2.7GHz bands. The 3.4-3.6GHz TDD band is perhaps the closest LTE has to a global band. It is licensed now in most of Asia, all of Europe, several other regions and the FCC has issued an NPRM for its use in USA</td>
</tr>
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<td><strong>Cost / Availability of Spectrum</strong></td>
<td>High prices paid for FDD allocations reflect the difficulties of freeing up suitable paired bands</td>
<td>Although becoming more expensive, unpaired bands are in general significantly cheaper per MHz. TDD bands offer the most realistic prospect for aggregated channel bandwidths of 40MHz and beyond</td>
</tr>
<tr>
<td><strong>Coverage</strong></td>
<td>FDD has been the mainstay of cellular technologies over the years, largely thanks to its suitability for large cell sizes</td>
<td>The coverage disadvantage is debatable (Coverage – The Great 3dB Debate). TDD comes into its own as cell sizes shrink - when capacity is the issue, rather than coverage</td>
</tr>
<tr>
<td><strong>Support for Beamforming</strong></td>
<td>Frequency separation of uplink and downlink channels makes implementation of closed loop schemes difficult</td>
<td>The TDD uplink and downlink are reciprocal supporting the use of advanced techniques</td>
</tr>
<tr>
<td><strong>Basestation Synchronization</strong></td>
<td>FDD requires frequency synchronization between basestations</td>
<td>TDD requires frequency and phase synchronization between basestations</td>
</tr>
<tr>
<td><strong>Use of Unpaired and Paired Spectrum</strong></td>
<td>Paired spectrum only (unless supplemental downlink is used)</td>
<td>Both paired and unpaired spectrum (subject to regulatory conditions)</td>
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Asymmetry – The TDD Trump Card

The 1% rule of thumb or 90:9:1 rule in Internet culture [10] suggests that in a group of 100 people online, 1% will create content, 9% will interact and 90% will just view it. This contributes to the asymmetric nature of the Internet.

This is supported by data and real-world experience.

Analysis of broadband data flow in real wireless networks shows significant asymmetry. The ratio DL/UL varies between operators and markets, but ratios of 5:1 and above are common. Even in the most conservative case a minimum ratio of 4:1 is seen.

Perhaps surprisingly, even for bi-directional type of applications such as P2P file sharing, the average uplink traffic is well below 50% of the total traffic (around 30%).

TDD systems can allocate time slices appropriately to match resources to the demand of the asymmetry – FDD cannot. That means that the effective capacity of the TDD system will be higher in the normal situations where the downlink capacity is the bottleneck of the system and where the uplink capacity is underused. There is also the gain effect that DL MIMO plays in favor of TDD asymmetric allocations (See Capacity – Using Downlink MIMO to the Advantage of TDD).

The use of supplemental downlink schemes in FDD is one attempt to address asymmetry using FDD, but lacks the real flexibility of TDD.

In practice the same DL/UL TDD network configuration needs to be applied to all basestations, however, 3GPP is considering fully dynamic TDD schemes for the future.
CAPACITY – USING DL MIMO TO THE ADVANTAGE OF TDD

Today in LTE, MIMO techniques are used universally in the downlink, but are not currently available in the uplink in most UEs with single transmission chain. As such, the asymmetric downlink to uplink ratio offered by TDD increases the aggregated throughput dramatically (simply because more traffic and more spectrum can take advantage of MIMO). As such, the more resources there are dedicated to the downlink, the more resources can apply MIMO and benefit for that better spectral efficiency. The same type of advantage can be seen with regards to modulation schemes which are more limited in the uplink (16QAM in uplink for current UE categories versus 64QAM in downlink).

This is slightly complicated by the impact of the TDD guard period, which does result in loss in capacity. However, in a small cell context this is reduced to a minimum (See The Guard Period for TDD Small Cells).

Simplistically:

If DL performance were to be doubled through use of MIMO, then the FDD case will result in an overall gain of:

\[0.5 \times 2 + 0.5 \times 1 = 1.5\] or a 50% overall increase

If this were a TDD system with 4:1 asymmetry (80%, 20%) then it would be:

\[0.8 \times 2 + 0.2 \times 1 = 1.8\] or an 80% overall increase

Modeling this in slightly more detail, assume we have single layer 16QAM in uplink, dual layer 64QAM in downlink and we allow for the guard timing. In this case it is simple to calculate the overall gains in capacity and spectral efficiency relative to FDD. Asymmetric, downlink-intensive TDD configurations will enjoy a total gain in capacity in comparison to the FDD case. The relative gain is even higher when considering only the downlink capacity, which is the more useful metric for traffic limited scenarios.

As such, MIMO and modulation benefits TDD over FDD in direct proportion to the DL/UL asymmetry. Obviously, the same gain will be seen in any other DL-based enhancements such as collaborative MIMO or CoMP. These will all benefit from the same ratio impact.
There are also other benefits from different areas too. For example, in smart antennas or beam-forming TDD also offers possible gains in capacity by using channel reciprocity, both to reduce the channel feedback signaling needed in the FDD case and to improve performance.

**The Guard Period for TDD Small Cells**

The frame structure for TDD (type frame 2) for a 5 ms switch-point is shown in the following figure.

![Guard Period Diagram]

The Guard Period accommodates the time necessary for the round trip propagation delay between the UE and the Small Cell, the UE switching delay (from reception to transmission) and the Small Cell switching delay (from reception to transmission). The minimum Guard Period of 1 symbol or 71µsec corresponds to the Special Subframe Configuration 4 or 8. This Guard Period corresponds to a maximum cell range of 5km which covers the Small Cell case.

<table>
<thead>
<tr>
<th>DwPTS/GP/UpPTS length (OFDM symbols)</th>
<th>Normal GP</th>
<th>Normal GP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Format</td>
<td>DwPTS</td>
<td>GP</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>1</td>
<td>9</td>
<td>4</td>
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<td>2</td>
</tr>
<tr>
<td>8</td>
<td>11</td>
<td>1</td>
</tr>
</tbody>
</table>

The loss in capacity associated with the GP for the typical Small Cell configuration would be in the order of 0.71% per 10ms frame (71µs for 1 DL to UL switch every 10ms) or 1.42% per 10ms frame (142µs for 2 DL to UL switch every 10ms).

Although there is some concern regarding this, it is clear that a loss of 0.71% is not significant.
**Coverage, Power – The Great 3dB Debate and an unexpected benefit of TDD**

The commonly heard argument for FDD is one of better coverage.

FDD systems transmit continuously and therefore require lower peak power at the transmitter for any given link budget than a TDD system occupying the same bandwidth. For example, let us compare a 2 x 5MHz FDD with a 10MHz TDD system. The TDD system transmits for half the time (assuming a symmetric uplink/downlink) whereas the FDD system transmits continuously. Therefore the TDD system requires 3dB more power to achieve the same performance in terms of energy per bit at the receiver. If maximizing range for a given peak ERP is the objective, FDD appears to have an advantage. Remember that, over the complete Tx/Rx cycle, both systems are consuming the same power – TDD uses twice as much power for half the time.

However, this argument applies in the extreme, and rather unlikely, case of a single user at cell edge consuming the total bandwidth of the cell. In more practical situations the coverage advantage of FDD over TDD is reduced or even eliminated - *“in a commercial environment where the cells have more than 1 user, the performance of FDD and TD-LTE, as demonstrated with 5 percentile edge throughput performance, will be very similar as the FDD device will not be able to access the full frame 10 UL resource blocks like he did on an unloaded single user network”* [9].

TDD does require a Guard Period in each frame to allow for the worst-case round trip propagation delay of the cell (See The Guard Period for TDD Small Cells). This has an impact on cell capacity for larger cell sizes, but presents a marginal overhead for small cells.

In the small cell context the objective is usually to optimize capacity, not range - to select the technology which optimizes other factors than simply coverage – efficient use of spectrum (through well-chosen UL/DL allocations), handset battery life and finally through advanced techniques such as beam-forming to optimize link budgets per user.

The fact that TDD can benefit battery life is important but not often appreciated. Because the signal uses a low-loss Tx/Rx switch rather than an inefficient duplexer the power used is significantly lower.

This has been pointed out in [8] - *“As there is no need for a duplexer in TDD Systems, typically the TDD systems will have >50% better battery life than FDD systems”*

Given that battery life is a key factor in user satisfaction and in handset choice, and that it is dominated by UL transmission and data usage, then the ability to increase battery life by >50% should be a major consideration for network operators.
The Economic Case: A Network Planning Blueprint

Let’s follow the argument to its logical conclusion. For frequencies below 2GHz it makes sense to continue to deploy large cell sizes for coverage in the “traditional” model. LTE FDD is appropriate for deployment here and fulfills the need for wide area coverage.

At higher frequencies, in particular the key bands from 2.3 – 2.7GHz and 3.4 – 3.6GHz, we argue that TDD should become the default technology assumption for urban deployment. Operators in possession of a paired frequency allocation may still adopt TDD technology, subject to local regulation and agreements (See Paired Bands may not necessarily mean FDD).

For example, in a capacity-limited deployment, TDD could increase the total capacity of the spectrum by up to 38% compared to FDD and the downlink capacity by up to 77%. This would be for an 8:1 asymmetry, which is observed in real cases. For a more conservative 6:2 ratio the improvements would be 26% and 54% respectively.

In order to maintain a certain QoE for the users, the FDD operator would need to deploy more cells in their FDD small cell network than a TDD competitor, with the corresponding increase in the Total Cost of Ownership (TCO).

The TCO for an LTE small cell deployment is almost entirely dominated by the per-node cost of small cell eNBs.

Unlike 3G deployments which required a HNB Gateway and dedicated core infrastructure, LTE small cells connect over the same S1 into the existing EPC, and use existing OSS/BSS. As such, there is no common fixed cost element, but there are variable (per node) costs:

- **CAPEX**
  - Cost of the actual eNB
  - Per node site acquisition & installation
  - Backhaul set-up & installation

- **OPEX**
  - Backhaul
  - Power
  - Site rental
  - OAMP

Since costs are almost entirely per node then the impact on TCO will be linear with the variable per node costs.
Accordingly, if a small cell deployment is dominated by downlink capacity (as is typical of small cell urban deployments) the LTE TDD case would increase downlink capacity by up to 77% compared to LTE FDD. For the same QoE and same effective capacity that implies FDD would need to increase TCO by 77% to match TDD, or to put it differently, the LTE TDD small cell TCO would be 44% lower.

In addition to this direct cost saving, it is worth noting that TDD spectrum has been cheaper ($/MHz/POP), and that LTE TDD enables operators to take advantage of “fallow” or otherwise unused spectrum - reducing spectrum investment and hence amortized cost.

We suggest that operators who adopt TDD will enjoy a significant technical and commercial advantage.
All Roads Finally Lead To LTE TDD

LTE finally delivers a single worldwide cellular standard after decades of battles and harmonization. The advantages and ecosystem acceleration that LTE TDD enjoys, especially for small cell deployments, ensure its global success, unlike its UMTS TDD/TD-SCDMA predecessors.

Technically, a key difference is that the LTE standard is broadly shared by both FDD and TDD modes. This reduces the incremental development cost and ensuring a broad eco-system.

Commerically, unlike UMTS TDD/TD-SCDMA, LTE TDD already has significant momentum. According to GSA, there are 54 commercial LTE TDD networks in deployment or firmly planned - including 16 commercially launched networks [11]. Six operators have launched combined FDD and TDD networks. Driven by this thriving ecosystem, ARCchart forecasts that LTE TDD subscriptions will surpass 500 million by 2017, representing annual LTE TDD operator service revenues of $91 billion worldwide.

Driven by large scale TDD spectrum availability and the technology's lower deployment costs, the industry witnessed several prominent LTE TDD network deployments including Softbank in Japan, Etisalat Mobily and STC in Saudi Arabia, and Bharti Airtel in India.

In October 2012, the LTE TDD ecosystem received a major boost when China’s Ministry of Industry and Information Technology announced that the entire 190 MHz of spectrum in the 2.6GHz band would be allocated for LTE TDD deployments in China, which harmonizes its TDD spectrum with Japan and the USA, two major LTE markets. In the Chinese market, China Mobile has already begun extensive commercial trials of LTE TDD and aims to roll out 200,000 LTE TDD base stations by the end of 2013 and 350,000 by the end of 2014.
All Roads Finally Lead To LTE TDD (continued)

Recently, in the UK LTE auctions, both BT and Vodafone paid significant premiums for access to LTE TDD spectrum.

Over 30 OEMs have commercially launched LTE TDD compatible devices. GSA goes on to say that 166 of the 821 devices i.e. 20% support the LTE TDD mode. LTE TDD devices are available in all form factors including smartphones, dongles, routers, portable hotspots, embedded modules, and mobile tablets. However, it is fair to note that infrastructure has been less well served: in particular there has not been any optimized small cell LTE TDD basestations, although that is now changing.

Paired Bands may not necessarily mean FDD

Depending on the applicable regulatory framework and regional or national agreements, an allocation of paired spectrum doesn’t have to be used for FDD. Technically it is quite possible to deploy TDD technology in such a situation as the figure below demonstrates.

Instead of one of the pair being used for UL and the other for DL, both can be used for DL/UL in a TDD system.

Indeed, as per the third example, they can be paired in a different sense: operating as TDD but aggregated (or “bonded”) to make a 40MHz TDD bearer.

![Example LTE Deployment Scenarios for 2 x 20MHz Paired Spectrum](image)

The specifics about whether this is permitted will vary by regulation and technical aspects (guard bands, band plans, etc.).

But it is worth emphasizing that the cost and TCO advantages from TDD deployments are potentially available not just to operators who own “TDD bands” but may be more widely applicable.
CONCLUSION

Historically, cellular has been dominated by FDD.

This White Paper shows how in a capacity dominated data context, TDD offers real technical and commercial advantages. In particular, by combining traditional FDD at the macro layer with higher-frequency TDD capacity-optimized small cells, operators can substantially improve spectral efficiency and reduce TCO.

TDD also provides flexibility to adapt networks to changes in usage patterns, applications or user profiles in the operator’s customer base and makes the small cell case yet more attractive for the operator.

We are facing a unique opportunity for a converged 4G worldwide wireless system based on LTE. This system has enough commonality between the LTE FDD and LTE TDD modes to reach unprecedented economies of scale, but most importantly, to manage the needed change in the deployment paradigm.

Specifically, adding LTE TDD small cells into the network can:

- Increase total capacity by up to 38%
- Increase downlink capacity by up to 77%
- Reduce Total Cost of Ownership by 44%
- Take full advantage of unused spectrum: reducing cost of spectrum acquisition and improving return on asset from currently wasted bands.
- Provide a simple path to wider channels (e.g., 40MHz)
- Improve UE battery life, potentially by >50%

Although historically there have been concerns and reservations about TDD (inefficiency of guard band, additional power, etc), this paper has shown these are not relevant in a small cell context.

This paper is a call to action to the industry and the regulators to move effectively, once and for all, from a voice-centric traditional symmetric communication paradigm to a data-centric, all-IP, flexible approach to data asymmetry. We have shown the clear arguments in favor of deploying TDD small cell solutions in the higher frequency bands and the opportunity which exists to maximize the effective capacity of this critical spectrum.
REFERENCES

[8] Timing the move to TD-LTE, Samsung
[9] TD-LTE Exciting Alternative, Global Momentum, Motorola