4G MULTI-MODE MULTI-BAND DEVICE REQUIREMENTS AND ARCHITECTURES

A GTI WHITE PAPER

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1 EXECUTIVE SUMMARY

This whitepaper identifies and explores the multi-mode multi-band device requirements of wireless network operators and service providers deploying the latest generation of mobile broadband technology, called LTE (Long-Term Evolution), using the time division duplex variant of the standard, known as TD-LTE. By defining a common set of frequency bands, 2G/3G technologies and other capabilities that should be supported by multi-mode, multi-band mobile global roaming smartphone devices, the GTI anticipates that the development of a TD-LTE device eco-system and certification process will be accelerated, while regional deployments and roaming capabilities will be facilitated. In addition, the paper highlights certain key LTE technological requirements related to multi-mode LTE mobility and MIMO support required by GTI operators.

Through surveys of GTI member companies, a set of recommended product specifications was developed for TD-LTE multi-band, multi-mode device designs to meet the immediate (2012-2013) needs of operators currently engaged in TD-LTE network deployments as well as the longer-range (post-2013) needs of operators still in the planning phase of their TD-LTE rollout. These recommended specifications include:

- LTE bands required to be supported in 2016 and beyond.
- Multi-Mode 2G/3G support.
- Support for voice and data applications.
- Support for FDD to TD-LTE mobility
- Support for MIMO configurations.
- Inter-frequency and intra-frequency carrier-aggregation (CA) requirements.
- Type of devices (i.e. smartphones, tablets, personal hotspot routers, data cards, CPEs).

LTE Bands. A set of seven core LTE bands were identified for inclusion in devices developed for 2016 deployments, which include four key TD-LTE band (Bands 38, 39, 40 and 41) as well as three FDD LTE bands (Bands 3, 7 and 20). Additional bands were identified as core roaming bands for 2016 deployments (Bands 1, 2, 4, 5, 8, 12, 13, 17, 25, 26, 27, 28, 42 and 43).

Air Interface Technology. In addition to support for both TD-LTE and FDD-LTE based on Release 9 3GPP features, 2G/3G technologies, along with WiFi, were identified as critical for the majority of GTI operators, namely GSM/EDGE/GPRS (in Bands 2, 3, 5 and 8) as well as HSPA/UMTS (in Bands 1, 2, 4, 5 and 8).

Voice and Data Applications. Simultaneous voice and data transmission capability was determined to be important to the majority of GTI operators and because 2G/3G technologies are expected to support voice services until VoLTE technology is available, CFSB mode was identified as the preferred approach by large operators with significant 3G networks. For those GTI operators continuing to operate 2G networks, the SVLTE through dual-stand-by device architectures was also noted to be an important consideration.

Mobility between FDD and TDD LTE. GTI operators require support for mobility between FDD and TD-LTE networks in various forms with full HO support between the two modes on LTE by Q2 2013.

MIMO. The majority of GTI operators listed MIMO technology as essential for achieving the throughput and efficiency targets for LTE. Prior to 2013, GTI operators have determined that support for Category 3 capabilities for LTE Release 8 and 9, as well as all eight required transmission modes (and required UL and DL signaling to function) are needed. The GTI operators determined that two separate transmit chains and amplifiers on devices is not necessary, but that an RF switch may be implemented initially. Beyond 2013, however, two TX UL schemes with dual dedicated TX chains, as well as beamforming, need to be supported.

Carrier-Aggregation. Carrier-aggregation (CA) was also identified as being an imperative for the GTI operators, with the majority indicating an interest in intra-band CA, along with some inter-band schemes. Support for inter-band CA of (20+20) MHz on the GTI core bands (38, 40, 41) is the most commonly requested capability. However, some GTI members also plan support for inter-band CA with Bands 39 (~1900 MHz) and 42/43 (~3500 MHz). GTI members plan to support CA among various FDD bands as well, including bands 1, 2, 3, 4, and 7.

Device Form Factors. A variety of device architectures were identified by GTI operators as important for their LTE deployment strategies, including smart phones, tablets, hotspot routers, USB/data cards, and CPEs. The majority of GTI operators indicated an initial requirement for smart phones with global roaming capabilities. Operators also indicated the need for data centric devices with regional roaming capabilities. GTI is currently working to further explore any global requirements for data only type devices.

2 INTRODUCTION

The Global TD-LTE Initiative (GTI) is an organization of wireless broadband operators worldwide cooperating in the promotion and development of a robust ecosystem based on the TD-LTE standard. Founded in February of 2011 by leading international mobile network operators, the GTI's mission is to:

1) Promote the convergence of TD-LTE and LTE FDD in order to maximize economies of scale

2) Energize the creation of a world-class, growth-focused business environment

3) Deliver great customer experience and bring operational efficiencies

4) Facilitate multilateral cooperation between and among operators

Initial LTE deployments occurred starting in mid-2010 and have been increasing at a pace that makes LTE the fastest developing mobile communication technology ever. However, these early deployments have largely been uncoordinated and have occurred in an ever-increasing number of frequency bands, making the implementation of the RF portion of LTE devices significantly challenging. To further complicate the device architectures, different mobile operators have different requirements with regard to support for voice services as well as interoperability with 2G and 3G networks.

Recognizing the complexity of developing devices that will address the disparate needs of LTE operators worldwide, GTI has formed several Task Forces to bring operators and vendors together for sharing development strategies and technology know-how, expediting the development of terminals, and fostering of global roaming and low-cost terminals, etc. One of these Task Forces, called Multi-Mode Multi-Band (MMMB), has focused on defining a common set of LTE bands and other device requirements in order to support regional deployments and roaming by accelerating the development of a device eco-system, including a certification process.

The MMMB conducted a number of surveys of the GTI operators to identify and harmonize common device requirements, architectures, and multi-mode multi-band needs. These requirements constitute the foundation for designing and manufacturing global roaming multi-mode multi-band devices serving the GTI community and beyond. This whitepaper is the culmination of the work of the MMMB task force and includes individual sub-sections summarizing the survey results on the following topics:

- LTE bands to be supported in 2016 and beyond.
- Multi-Mode 2G/3G support.
- Support for voice and data applications.
- Support for MIMO configurations.
- Inter-frequency and intra-frequency CA requirements including CA configuration schema.
- Type of devices (i.e. smartphones, tablets, personal hotspot routers, data cards, CPEs) required to support business cases.

This paper is organized as follows;

- Section 3 presents some of the key challenges associated with multi-mode multi-band devices due to increased number of bands required to be supported, fragmentation of those bands, and legacy technology support.
- Section 4 then focuses on GTI requirements for those multi-mode multi-band devices, particularly in the case of smartphones which are the main global device form factors. Requirements are presented in key areas that affect smartphone design, architectures, and functionality such as; multi-band LTE support, support for legacy wireless technologies, mobility between both modes of LTE standard (i.e. FDD and TDD), MIMO configuration required to be supported on those devices, and carrier aggregations. All these requirements were derived as part of an extensive operator survey.
- Section 5 addresses some of smartphone device architectures that could be useful to implement GTI requirements. In addition, architectures related to data only devices such as hotspot routers, tablets, CPE, and USB are discussed.
- Section 6 then summarizes key recommendations of this work and highlight future areas of that GTI will focus on in order to achieve its goal and objectives.

3 MULTI-MODE MULTI-BAND DEVICE CHALLENGES

GTI operators are currently engaged in major LTE deployment plans in 2016 timeframes. However, despite the fact that LTE proves to be the fastest developing mobile communication technology ever [7], there will still be a need for multi-mode (i.e. 2/3G and LTE) devices for several years to come before LTE coverage matches that of existing 2G-3G networks.

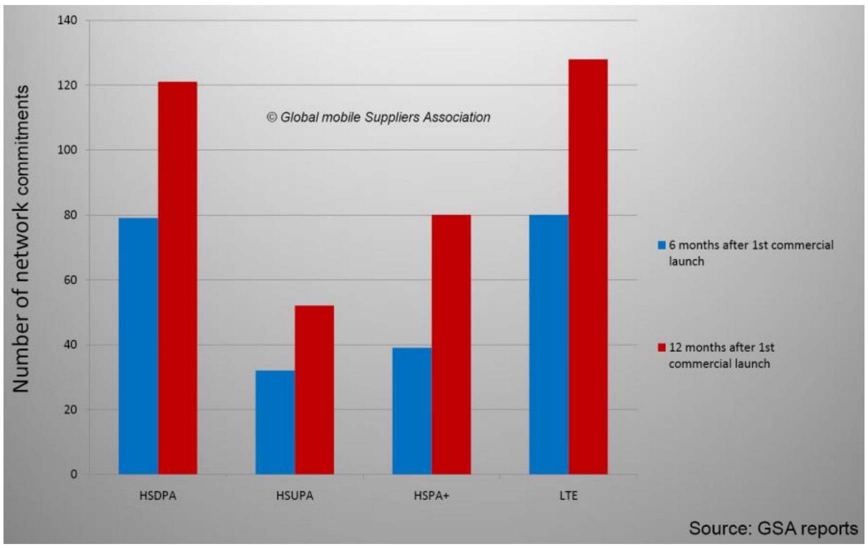

Figure 1–HSPA vs LTE technology embracement [7]

Furthermore, several GTI operators may opt to build a 4G capacity oriented network in order to handle more efficiently capacity constraints rather than build a nationwide coverage network. Therefore, GTI operators would need to offer multi-mode capable devices in order to provide their subscribers with the ability of obtain services across the largest coverage area.

In addition, as various operators may use different LTE bands, the number of which is constantly increasing, any global roaming LTE device would also require support for, at least, a set of core LTE bands in order to facilitate roaming. It is only through the re-use of the same hardware device architectures and electronic components that will benefit when economies of scale will kick in and lower cost global smartphones may become available to a larger pool of customers.

All these multi-mode multi-band requirements along with technology features such as increased channel bandwidth (i.e. up to 20MHz per carrier), MIMO, multi carrier aggregation (i.e. CA), support for simultaneous voice and data support in different forms, undoubtly impose significant challenges in terms of device architectures, size, power consumption, processing power, and software complexity related to inter-RAT selection and mobility.

To that effect, GTI has established a working group to analyze common operator requirements and harmonize device requirements, architectures, and multi-mode multi-band needs among its members. Those requirements would then constitute the foundation for designing and manufacturing global roaming multi-mode multi-band devices serving the GTI community and beyond.

4 GTI MM-MB DEVICE REQUIREMENTS

In order to gather GTI's operator requirement a comprehensive survey was conducted gathering information on key technological areas that have a direct implication on device architectures and MM-MB support. In addition, the survey took into account various timeframe requirements (i.e. 2012, 2014/15) in order to accommodate for an incremental approach when applicable. It is well understood that device requirements and MM-MB support will evolve over time and such evolution along with device market lifespan should be considered when deciding global device requirements. The following requirement areas were covered as part of the survey;

- LTE bands required to be supported in 2016 and beyond.
- Multi-Mode 2G/3G support.
- Support for voice and data applications.
- Support for MIMO configurations.
- Inter-frequency and intra-frequency CA requirements including CA configuration schema.
- Type of devices (i.e. smartphones, tablets, personal hotspot routers, data cards, CPEs) required to support business cases. The following subsections of this paper summarize some of the survey results pertaining to above mentioned areas.

4.1 LTE MULTI-BAND REQUIREMENTS

This subsection will summarize requirements as it pertains to main LTE bands of interests, roaming LTE bands, and timeframes as to when those bands will be required based on LTE deployment plans from GTI members.

Initial LTE deployments occurred in mid-2010 and since then the technology has been deployed with such a pace that is making it the fastest developing mobile communication technology ever. However, these deployments are happening in disjoint and with an ever increasing number of frequency bands which makes RF implementation of devices even more challenging. To further complicate the device architectures, different mobile operators have different requirements with regard to voice support on 4G LTE devices. Some support voice features through Circuit Switch Fall Back (i.e. CSFB) mechanism, others require Simultaneous Voice and LTE (i.e. SV-LTE) by using 2/3G technologies for voice while maintaining data session connection on LTE. In this context, GTI's has engaged with its operator base, a base that today encompasses more than one billion customers, to define a common set of multi-mode multi-band device configuration in order to accelerate global 4G device ecosystem and device development by maximizing economics of scale.

Table 1 summarizes the operator response regarding their immediate needs for LTE band support as well as what is expected to be needed by 2016 and beyond. It is believed that partitioning the requirements into those various timeframe would help the development of global 4G configured smartphones for 2016 and beyond by defining more realistic device configuration that address immediate needs while setting the foundation for future developments in the years to come.

Operators	Required LTE Bands																						VoLTE
	TD-LTE						FDD LTE																
	B-38	B-39	B-40	B-41	B-42	B-43	B-1	B-2	B-3	B-4	B-5	B-7	B-8	B-11	B-12	B-13	B-17	B-20	B-25	B-26	B-27	B-28	
C-1																							
C-2																							
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C-41																							
C-42																							
C-43																							
C-44																							
Total	**12**	**2**	**13**	**13**	**24**	**15**	**14**	**4**	**8**	**6**	**8**	**11**	**10**	**7**	**2**	**3**	**5**	**5**	**1**	**4**	**1**	**6**	**25**

LTE Bands of Interests in 2016
LTE Bands of Interests in 2017
LTE Bands of Interests in 2018
LTE Bands of Interests in 2019
LTE Bands of Interests in 2020
LTE Bands of Interests Expressed Deployment Plan Pending

Table 1. GTI Operator LTE band requirements

GTI has identified seven LTE core bands that will be required for global smartphone devices:

- LTE bands 40/38/7/41 distributes in 2.3GHz-2.7GHz range, which are the highest number of bands required by GTI operators. Those Quad-LTE bands constitute a single frequency range for 4G worldwide roaming with mass market opportunity covering more than 50% of world's population (i.e. China, India, US, Europe, Russia, Japan).
- Band 39 distribute in around 1.8GHz which are of strategic importance with significant important in Asia.
- FDD bands 3 and 20, which are more centric to early European deployments.

Mode Type	Band No.	Uplink	Downlink
TD-LTE	Band 38	2570-2620MHz	2570-2620MHz
	Band 40	2300-2400MHz	2300-2400MHz
	Band 41	2496-2690MHz	2496-2690MHz
	Band 39	1880-1920MHz	1880-1920MHz
FDD LTE	Band 3	1710-1785MHz	1805-1880MHz
	Band 7	2500-2570MHz	2620-2690MHz
	Band 20	832-862MHz	791-821MHz

Table 2. GTI LTE Core Bands Frequency Definition and Timeframe Requirements

In addition to core LTE bands, GTI operators require support for certain roaming bands as well. 错误！未找到引用源。 shows the additional GTI roaming bands by 2016.

Mode Type	Band No.	Uplink	Downlink
FDD LTE	Band 1	1920-1980MHz	2110-2170MHz
FDD LTE	Band 2	1850-1910MHz	1930-1990Mhz
FDD LTE	Band 4	1710-1755MHz	2110-2155MHz
FDD LTE	Band 5	824-849MHz	869-894MHz
FDD LTE	Band 8	880-915MHz	925-960MHz
FDD LTE	Band 12	699-716MHz	729-746MHz
FDD LTE	Band 13	777-787MHz	746-756MHz
FDD LTE	Band 17	704-716MHz	734-746MHz

FDD LTE	Band 25	1850-1915MHz	1930-1995Mhz
FDD LTE	Band 26	814-849MHz	859-894MHz
FDD LTE	Band 27	807-824MHz	852-869MHz
FDD LTE	Band 28	703-748MHz	758-803MHz

Table 3. GTI FDD LTE Core Roaming Bands Required in 2016 and beyond

GTI is also currently analyzing the global needs and requirements of its members for support of 3.5GHz TD-LTE bands (i.e. bands 42/43), as those bands show good potential in various parts of the world and several operators will be using those bands for LTE deployments.

Mode Type	Band No.	Uplink	Downlink
TDD LTE	Band 42	3400-3600MHz	3400-3600MHz
TDD LTE	Band 43	3600-3800MHz	3600-3800MHz

Table 4. GTI TDD LTE Core Roaming Bands Required in 2016 and beyond

4.2 DEVICE MULTI-MODE REQUIREMENTS

As mentioned chapter 4.1, the LTE terminal should be compatible with 2/3G mode at the initial stage of LTE deployment, which means not only LTE bands but also 2/3G bands are required by GTI members. In addition, some 2/3G bands will be re-farmed for LTE deployment, and can co-band with LTE in the device, which will not necessarily cause any additional increase of cost.

Table **5** summarizes the survey results in this area. Based on survey results GSM/EDGE/GPRS/HSPA constitutes2/3G technologies required by GTI for global configuration devices. Wi-Fi is also a required technology by various operators. However, WiMAX is not required to be supported in a multi-mode smartphone configuration.

Operators	Multi-Mode Requirements																
	Technology Type								Bands Required								
	GSM	GPRS	EDGE	HSPA	EV-DO	TD-SCDMA	WiMAX	WiFi	B-1	B-2	B-3	B-4	B-5	B-7	B-8	B-34	B-39
C-1				■					■		■						
C-2	■			■					■	■	■	■			■		
C-3	■	■	■	■		■		■	■	■	■		■		■	■	■
C-4				■	■			■	■		■		■				
C-5	■	■	■	■					■		■				■		
C-6	■	■		■			■	■	■		■	■	■		■		
C-7				■					■	■		■					
C-8				■				■	■								
C-9	■	■		■			■			■	■	■	■				
C-10				■			■		■		■				■		
C-11				■			■		■								
C-12	■	■	■	■			■		■		■	■	■				
C-13	■	■	■	■					■		■				■		
C-14	■			■													
C-15	■	■	■	■					■	■	■		■		■		
C-16				■				■	■	■	■						
C-17	■				■		■	■		■	■						
C-18	■	■		■			■				■						
C-19	■		■	■						■			■				

Table 5. Multi-Mode survey results

Table 6 and Table 7 depict the technologies and bands required in by GTI operators for their global roaming multi-mode multi-band smartphones.

Mode Type	Band No.	Uplink	Downlink
GSM/EDGE/GPRS	Band 2	1850-1910MHz	1930-1990Mhz
GSM/EDGE/GPRS	Band 3	1710-1785MHz	1805-1880MHz
GSM/EDGE/GPRS	Band 5	824-849MHz	869-894MHz
GSM/EDGE/GPRS	Band 8	880-915MHz	925-960MHz

Table 6. GTI GSM/EDGE/GPRS Band requirements

The HSPA/UMTS bands required by GTI are bands 1/2/5/4/8:

Mode Type	Band No.	Uplink	Downlink
HSPA/UMTS	Band 1	1920-1980MHz	2110-2170MHz
HSPA/UMTS	Band 2	1850-1910MHz	1930-1990Mhz
HSPA/UMTS	Band 5	824-849MHz	869-894MHz
HSPA/UMTS	Band 4	1710-1755MHz	2110-2155MHz
HSPA/UMTS	Band 8	880-915MHz	925-960MHz

Table 7. GTI UMTS/HSPA Band requirements

Based on the information presented in Sections 4.1 and 4.2 a GTI multi-mode multi-band global roaming smartphone device should comply with the following configuration;

3GPP Band	Technology Support Req.
1	UMTS/HSPA/LTE
2	GSM/EDGE/UMTS/HSPA
3	GSM/EDGE/UMTS/HSPA/LTE
4	GSM/EDGE/UMTS/HSPA/LTE
5	EDGE/UMTS/HSPA
7	LTE
8	GSM/EDGE/UMTS/HSPA
12	LTE
13	LTE
17	LTE
20	LTE
25	LTE
26	LTE
27	LTE
28	LTE
38	LTE
39	LTE/ TD-SCDMA
40	LTE
41	LTE
42	LTE
43	LTE

Table 8. GTI global roaming multi-mode multi-band requirements.

As shown in Table 8, this configuration supports nineteen bands, fourteen of which are purely LTE bands. To that end, this configuration builds on already supported Quad-GSM and UMTS smartphone designs by adding support for new LTE bands. Furthermore, as six of fourteen LTE bands (i.e. 7,38,40,41,42 and 43) use frequencies that do not overlap with previously used frequencies (i.e. below 2.1 GHz), their introduction into a smartphone design could be achieved through innovative and cost effective solution that make those bands seen as a single entity from a device RF front-end architecture. IWPC has recently published a detailed analysis on 2.3-

2.7GHz device RF front-end architectures and proposed two optimized architectures to address those bands in an effective and well performing design [9]. OEMs are encouraged to review that prior to engage in any design addressing GTI's core LTE bands 3,7,20,38,39,40 and 41.

4.3 VOICE AND DATA SUPPORT

Voice service is a key application for most operators across the world. Despite the recent growth of mobile broadband and smartphones, the bulk of cellular industry revenues still come from voice applications. Irrespective of the rapidly rising volumes of data traffic and the need for more capacity and speed, it is clearly important for operators to retain the ability to deliver a good voice experience, on any radio network deployment intended for a broad audience.

While the ultimate intention is to exploit LTE's lower latency and QoS features to provide comparable (or better) voice services than those possible on traditional circuit switched networks, it is well recognized that initial LTE network deployments would have to support voice services based on interaction with other technologies. This is mainly for three reasons:

a) It will be sometime for LTE deployments to achieve nationwide coverage, hence multi-mode devices would have to support voice services on 2/3G technologies during this time.

b) It will take considerable time to gain sufficient experience in tuning the network and devices for mass market mobile VoIP like applications.

c) There are also concerns that any option should not make it too much more difficult to manage aspects like roaming, emergency calling, supplementary services and so forth.

At last, four approaches are generally discussed as possible commercial choice to support voice application in a network configuration supporting LTE:

1) Circuit Switched Fallback (CSFB)

2) Dual Standby or Simultaneous Voice-LTE (SVLTE)

3) Single Radio Voice Call Continuity (SRVCC)

4) Voice Over LTE (VoLTE)

4.3.1 CIRCUIT SWITCHED FALLBACK (CSFB)

CSFB was introduced in 3GPP Rel-8 (TS 23.272) to allow an UE in EPS to reuse CS domain services by defining how the UE can switch its radio from EUTRAN access to other RAT (e.g. GERAN/UTRAN/1xRTT access) that can support CS domain services. With CSFB approach, the LTE just provides data services and when a voice call is to be initiated or received; it will fall back to the CS domain.

There are multiple mechanisms of network selection / service initiation depending on the user types. For data centric users, the UE shall attach and continue to stay on LTE (as far as LTE coverage available) until the voice service is initiated. Upon initiation of voice service, UE will fall back to 2G / 3G. Upon termination of voice service, the UE may return back to LTE (if available).

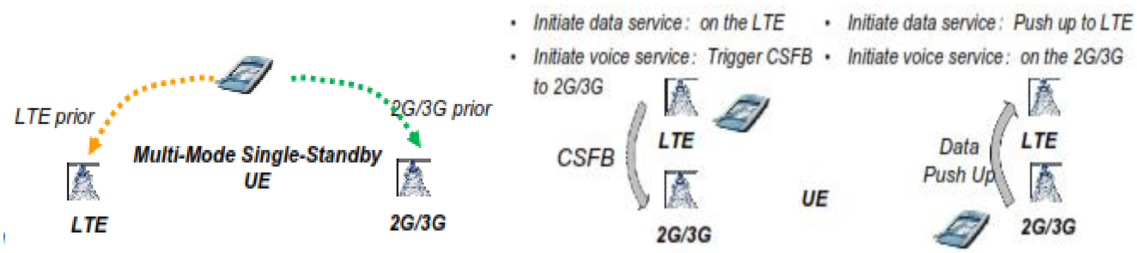

Figure 2. CSFB transition modes.

For voice centric users, the UE shall attach and continue to stay on 2G/3G till the data service is initiated. Upon initiation of data service, UE is push up to LTE (if available). Upon termination of data service, the UE may return to 2G/3G.

CSFB mechanism has little implication on device side, particularly hardware wise, and leads to lower power consumption when compared to some other schemes. However, the call set-up time may be longer than expected in certain cases.

4.3.2 DUAL STANDBY / SIMULTANEOUS VOICE-LTE (SVLTE)

Multi-mode dual-standby single-USIM approach uses terminals which can access two cellular networks simultaneously via one USIM card and implement the authentication of terminal and integrated HLR/SAE HSS.

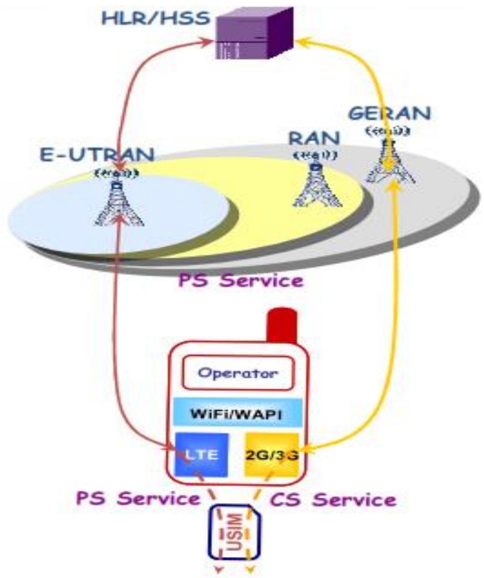

Figure 3. Dual Stand-By network architecture.

Below are the features of Dual-standby:

1) Able to standby and work in LTE network and 3G (or 2G) network simultaneously.
2) Support LTE PS service and 3G (or 2G) CS service concurrently on the UE.
3) In LTE and 3G (or 2G) network coverage area, UE only attaches LTE PS and 3G (or 2G) CS.
4) If there is no LTE network coverage, only with 3G and 2G network coverage, UE will attach both PS and CS via 3G or 2G.

GTI has already published a dedicated paper on LTE multi-mode dual-standby Single-USIM devices [[8]] and readers are encourage to consult that document for more information about this subject, its advantages and disadvantages when compared to other options.

It should be mention that while dual-standby and SVLTE may refer to different type of voice technology support, they are very similar when it comes to device hardware architectures. Both those variants would require voice support in a circuit switch domain (i.e. one case may use CDMA the other 2G/3G technologies) band while LTE data transport is maintained in a separate band. Therefore, the differences in device architecture may rely on the USIM access mechanism, which could be potentially more complex in the case of dual standby. In addition, there significant differences between dual stand-by and SVLTE on core network functionality and interconnection, but that is outside the device scope considered in this paper.

4.3.3 SINGLE RADIO VOICE CALL CONTINUITY (SRVCC)

SRVCC is an LTE functionality that allows a VoIP/IMS call in the LTE packet domain to be moved to a legacy voice domain (GSM/UMTS or CDMA 1x). It offers LTE-IMS based voice service within the LTE coverage area and CS-based voice service outside the LTE coverage area. Whenever the VoIP subscriber moves out of LTE coverage, SRVCC ensures smooth handoff of voice from the LTE to the CS network, keeping upgrades of the network to a minimum.

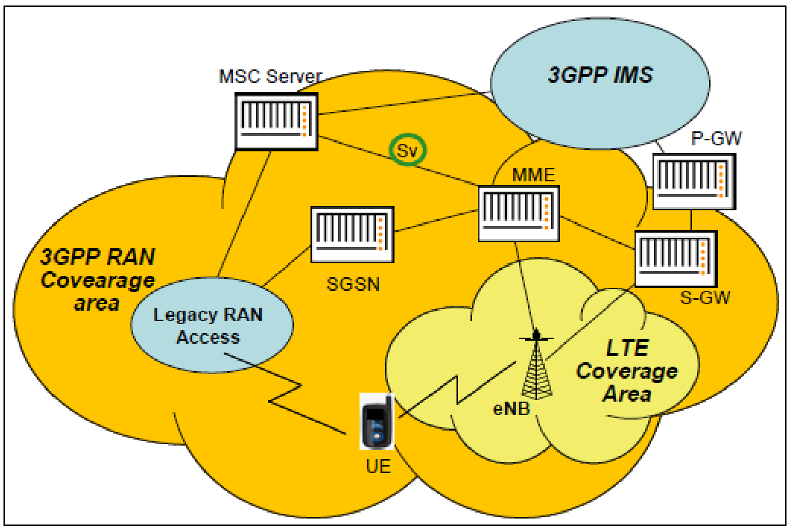

Figure 4. SRVCC network architecture[10].

With SRVCC approach, the SRVCC-capable UE's engaged in a voice call determines that it is moving away from LTE coverage, it notifies the LTE network. The LTE network determines that the voice call needs to be moved to the legacy circuit domain. It notifies the MSC server of the need to switch the voice call from the packet to the circuit domain and initiates a handover of the LTE voice bearer to the circuit network. The MSC server establishes a bearer path for the mobile in the legacy network and notifies the IMS core that the mobile's call leg is moving from the packet to the circuit domain. The circuit-packet function in the IMS core then performs the necessary inter-working functions. When the mobile arrives on-channel in the legacy network, it switches its internal voice processing from VoIP to legacy-circuit voice, and the call continues.

If operators look to limit LTE deployments to high traffic areas and at the same time wish to transition voice service in those areas to VoIP, then SRVCC is exactly what they need.

SRVCC has the advantage of low call set-up time and UE implementation is less complex and expensive. However, it imposes additional requirements on network side due to its IMS core reliance.

4.3.4 VOICE OVER LTE (VOLTE)

The Voice over LTE scheme was devised as a result of operators seeking a standardized system for transferring voice traffic over LTE. The aim for VoLTE is to utilize the low latency and QoS features available within LTE to ensure that the voice service offers an improvement over the standards available on the 2G and 3G networks. Introduction of HD voice and video codecs can significantly improve call quality. VoLTE would offer certain advantages over other schemes, such as;

1) Flexible design due to all IP implementation.
2) Call setup time of VoLTE will be dramatically shortened compared to pre-VoLTE options.
3) HD voice and video codecs can improve call/voice quality significantly.

However, it is well understood that the maturity of this feature would require sometime prior to becoming main stream technology for LTE networks.

4.3.5 SURVEY RESULTS

GTI operators were surveyed regarding the preferences they had for supporting voice services in their networks. The table below depicts results of that survey:

Operators	Voice and Data Requirements				
	Simulataneous Voice+Data	Voice Technology(2/3G)	Dual-Standby	CSFB	VoLTE/Year
C-1	Required	2G and 3G		Required	Required
C-2	Required	2G and 3G		Required	Required
C-3	Required	2G and 3G	Required	Optional Support/Undecided	Optional Support/Undecided
C-4	Required	2G and 3G	Optional Support/Undecided	Optional Support/Undecided	2013 (Required)
C-5	Required	2G and 3G	Required	Required	
C-6	Required	2G and 3G	Required	Required	Required
C-7					
C-8	Required	2G and 3G	Optional Support/Undecided	Required	Required
C-9	Required	2G and 3G	Required	Required	2013 (Required)
C-10	Required	2G and 3G	Required		
C-11	Required	2G and 3G	Required		Required
C-12	Required	2G and 3G			Required
C-13	Required	2G and 3G		Required	Required
C-14	Required	2G and 3G			2013 (Required)
C-15	Required	N/A			Required
C-16	Required	N/A			Required
C-17		N/A			2013 (Required)
C-18	Required	2G and 3G	Optional Support/Undecided	Optional Support/Undecided	Required
C-19	Required	2G	Optional Support/Undecided	Optional Support/Undecided	Required

Optional Support/Undecided (yellow)
Required (green)

Table 9. Operator voice support technology requirements.

Survey results indicate that simultaneous voice and data transmissions support is a key requirement for GTI operators and any device serving their needs need to provide support for such functionality. The implementation of such functionality is addressed by two configurations;

1) GTI operators with significant 3G network deployments require support for CSFB, as the performance of this approach is considered acceptable.

2) However, a large constituency of GTI operators currently own only 2G networks and they have expressed concern about the current performance of CSFB in such a configuration. Therefore, they require support for SVLTE through dual-stand-by device architectures.

In addition to the current state of requirements, there is an overwhelming desire to migrate to VoLTE in the upcoming years.

4.4 FDD TO TD-LTE MOBILITY REQUIREMENTS

As shown in Table 1, GTI operators require support for TD-LTE and FDD LTE bands. And as such, there is a need to support mobility between those two modes of LTE technology in order to provide a seamless user experience as he moves around between networks or even within the same operator network supporting both modes.

GTI expects that mobility could be achieved in various options or phases, with the ultimate goal of full connected mode mobility support. Table 10 shows the phasing of inter-duplex mode mobility, and the expected time of support.

Q2-2012	RRC Connection Release with Redirection procedure with target eNB measurement, which could be suitable for data application.
Q2-2012	Idle Mode Mobility support through cell Re-Selection procedures.
Q4-2012	Full support for FDD to TDD HO if UE capabilities are identical for FDD and TDD.
Q2-2013	Full support for HO between FDD and TDD LTE in RRC connect mode if UE capabilities are different between FDD and TDD.

Table 10.FDD to TD-LTE and vice-versa mobility requirements.

Early work has focused on mobility within networks and between similar networks, but GTI members have also worked to fully define mobility scenarios between duplex modes. GTI operators in conjunction with their partners worked diligently within 3GPP to accelerate RAN5 RRM system mobility tests cases related to cell selection, handover and measurements sections.3GPPRAN plenary meeting held in March 2012 in Xiamen, China, approved significant contributions related to LTE inter-duplex mobility between FDD and TDD and those modifications are now part of TS 36.331 V9.10.0 (2012-03) specifications [11].

GTI is also working very closely with LTE chipset vendors to fully define and finalize HO RRC connect state solution between FDD and TDD LTE.

4.4.1 UE CAPABILITIES

One of the challenges in support of mobility between FDD and TDD systems is with UE capabilities. As of March 2012, LTE technology now officially has a full dual-mode FDD/TDD mobility/HO solution, which all UE vendors can support, with streamlined mechanism that resolves the lower level UE capability/FGI issues for each mode [11]. GTI requires full compliance with this version of 3GPP 36.331 specs.

4.4.2 MEASUREMENTS

To support inter-band mobility, GTI requires that UEs support connected mode measurements across bands of interest. The UE reports this support in bits 25 of the Feature Group Indicators (FGI) in the UE capabilities, and the UE must be capable of performing these measurements during standard measurement gaps, as specified by Release 9 of 3GPP specs.

Measurement objects are configured by the eNB. In the RRC_IDLE state, the UE picks up the measurement configuration from the System Information Type 5 message broadcast by the eNB. In the RRC_CONNECTED state, the eNB may send dedicated measurement configuration information to the UE in an RRCConnectionReconfiguration message, overriding the broadcast configuration.

Measurement can be configured for either periodic or event-triggered reporting, and multiple measurement objects with different triggers can be configured simultaneously. The details of the measurement configuration will likely vary depending on the unique needs of the operators.

4.4.3 FDD/TD-LTE MOBILITY THOUGH RELEASE /REDIRECTION MECHANISM

In the first phase of deployments, mobility may be achieved through a redirection procedure. This procedure, which is deemed more than adequate for data applications, can be supported between eUTRANs that do not have interconnections between their eNBs. The eNB need only know the carrier center frequency of the target network cells with coverage overlapping its own.

The eNB configures measurements for the UE as described above. Based on measurement reports from the UE and/or loading information from the network, the eNB may decide to "push" the UE to another eUTRAN. The serving eNB sends an RRCConnectionRelease to the UE with redirection information to move the UE to the RRC_IDLE state and cause the UE to initiate cell reselection to the target. The redirection information is included in either the redirectedCarrierInfo IE or the idleModeMobilityControlInfoIE.

UEs must be able to correctly handle this redirection command, reconfiguring their RF front end to operate on the targeted band and center frequency. The UE will then search for a cell on the designated frequency and establish a new connection with the eNB with an RRC connection establishment procedure.

Redirection based mobility is expected to be sufficient for most non-real-time applications. Depending on the interconnections between the FDD and TDD networks, the UE will maintain the same IP address. The connection outage will be virtually unnoticeable for most users – under ~400ms, depending on core network architectures and topologies. Many streaming media applications use heavy buffering, and will be unaffected by durations this short.

4.4.4 HANDOVER BETWEEN FDD/TD-LTE IN RRC CONNECT STATE WITH IDENTICAL OR ARBITRARY UE CAPABILITIES

Later phases of deployment may require connected mode handover between FDD and TDD cells. FGI Bit 30 indicates UE capabilities to support FDD/TDD LTE HO.

Connected mode handover yields shorter data outages and so supports more delay sensitive services. If the UE's capabilities are identical between FDD and TDD, then the UE can safely hand over between the two types of networks with both networks being aware of those capabilities.

The eNBs involved in the handover must have an interconnection, S1 or X2. The X2 interface is between two eNBs, and would allow faster handovers and exchange of loading information. Handover is also possible using the S1-MME interface when the eNBs have connections to a common MME (or connected MMEs) and a direct X2 connection is not available.

Just as with Redirection, handover will normally be triggered by UE measurements and/or eNB loading information. When the eNB decides to initiate a handover procedure, it first sends a Handover Request message to the target eNB. If the target eNB can accept the UE, it responds with a Handover Request Ack message. The serving eNB then sends an RRCConnectionReconfiguration message to the UE handing the UE over to the target eNB.

Once the UE has connected to the new network, the target eNB sends an S1 Path Switch Request to the MME, triggering the UE's data path to be moved to the new eNB.

Because of the standards gap with UE capabilities discussed above, in early deployments this procedure will require that UEs have identical capabilities with FDD and TDD operation. Since the target eUTRAN will learn of the UE capabilities from the previous serving eUTRAN, the UE capabilities cannot change. GTI members require UEs to have the ability to operate in this way when so configured and are encouraged by the fact that several chipset vendors will support this functionality in 2012.

Connected mode handover allows much shorter connections delays, supporting real-time services such as un-buffered streaming media and VoIP/VoLTE.

4.5 MIMO SUPPORT

MIMO (Multiple Input Multiple Output) technology helps LTE achieve ambitious throughput and spectral efficiency targets (reaching up to 30 bps/Hz in Rel 10 LTE-Advanced), which are essential for supporting broadband data services over wireless links. Various forms of MIMO exist in the E-UTRAN specifications from LTE Rel 8 onwards, with further enhancements in Rel 9 and Rel 10. Benefits that MIMO provides include improved signal quality at cell edge and higher throughput through parallel transmission of multiple data streams. MIMO thus significantly increases channel capacity.

MIMO technology requires the following to function:

- at least 2 transceivers at both transmission and reception ends
- better SNR than single antenna configurations, and
- added computational complexity

MIMO signal recovery is a 2-stage matrix process:

- Recovering channel coefficients (from pilot subcarriers)
- Separating and demodulating the signals

4.5.1 MIMO TYPES AND CONCEPTS IN LTE

Multiple antenna technology in LTE is designed around three main variants of technology;

- Spatial Multiplexing
  - Transmit different streams of data simultaneously within the same resource block(s). The streams can be owned by a single user (SU-MIMO) or multiple users (MU-MIMO). Each transmit antenna sends a different (unique) stream,

when channel conditions are suitable. This effectively multiples a channel's throughput by the number of streams and results in higher data rate.

- Data is arranged in time-frequency "layers"; In Rel-8/9/10, on the UL a single layer per terminal is used, and on the DL up to 4 layers are supported.

- Transmit Diversity
    - When RF conditions are too poor for spatial multiplexing, transmit diversity is used. Each transmit antenna sends the same signal. In real-time communications between the eNodeB and the UE will determine which UE antenna is to be used for transmission.
    - No signaling is used for conveying how many transmit antennae are used; as this is automatically decoded and determined by the receiver.
- Beamforming
    - Used to improve data coverage when the UE supports UE-specific reference signal decoding. Using its individual antenna array elements, the eNodeB generates a beam and precodes both the UE-specific reference signal and the data payload with the beam.

In Rel 9, each UE is configured into one of 8 transmission modes, as described in Figure 5, that use various combinations of Spatial Multiplexing and TX Diversity, layers and MU-MIMO.

Transmission Mode	Description	Comments
TM1	Single antenna port: port 0	SISO or SIMO Common RS
TM2	Transmit diversity (TxD)	Typically performs better in low SINR Robust to high speed Fallback schemes for TM3-8
TM3	Open-loop spatial multiplexing (SM)	Potentially better than TD in high SINR and rich scattering
TM4	Closed-loop spatial multiplexing (SM)	Potentially benefit over CL Rank 1 and TD in high SINR rich scattering Potential better than OL SM at low speeds
TM5	Multi-user MIMO	Rank 1 precoding per UE, unaware of other UE, need to find two orthogonal Ues
TM6	Closed-loop Rank=1 precoding	Typically better than SM in low SINR Potentially better than TD at low speeds
TM7	Single antenna port: Port 5	Antenna Arrays single layer BF Dedicated RS
TM8	Dual-antenna port: port 7 / port 8	Antenna Arrays single layer BF, dual layer BF, MU-BF Dedicated RS

Figure 5.LTE TM summary.

4.5.2 OPEN LOOP TX DIVERSITY VERSUS CLOSED LOOP

- Open loop does not use channel feedback data and is more suitable for low-mobility environments. In this case, the UE will select by itself which antenna it should transmit through.
- Closed-loop is more suitable for mobile environments and the eNodeB will signal to the UE which antenna it wants it to transmit through using the reported PMI or Pre-coding Matrix Indicator value.

Based on GTI operator survey, the following are the MIMO requirements;

- Support for TM 1-6 by end of 2012 with TM-5 considered as optional.
- Support for all other TMs by 2013.
- Support for 2Tx UL transmission schemes, particularly for data type devices, by 2014. This schema should be based on a 23dBm transmit power per branch, which requires amendments to 3GPP specs. GTI is working with various partners to recommend such changed to 3GPP standards.
- 4x4 to be supported on CPE devices by 2014.

4.6 CARRIER-AGGREGATION REQUIREMENTS AND THEIR IMPACT ON DEVICE REQUIREMENTS

Most GTI members plan to utilize the Carrier Aggregation features defined in Rel-10. Carrier Aggregation (CA) allows the use of “bonded” carriers by a single device. Supporting device can use multiple component carriers to increase single user throughput, or perhaps more importantly, to improve the efficiency of load balancing between the component carriers.

The CA mechanism is defined very flexibly, allowing aggregation between contiguous or non-contiguous carriers, between carriers on different bands, between carriers with different bandwidths, and with different configurations on UL and DL. GTI members plan to use all of these features. Table 11 shows the GTI operator survey results regarding CA feature.

Companies	CA Requirements																				
	Intra-Band Requirments		Inter-Band Requirements														CA Configuration				
	Req.	CC Cfg.	Req.	B-1	B-2	B-3	B-4	B-7	B-8	B-20	B-38	B-40	B-41	B-42	B-43	CC Cfg.	DL Only	UL Only	DL+UL	Sym.	Asym.
C-1																					
C-2	TBD		TBD																		
C-3	YES	(20+20)MHz	NO																		
C-4	YES	(20+20)MHz	NO																		
C-5	NO		YES													10MHz+10MHz					
C-6	YES		YES													20MHz+5MHz/20MHz+10MHz/20MHz+15MHz					
C-7	Yes	(20+20)MHz	TBD																		
C-8	YES	(10+10)MHz	Yes													10MHz+10MHz 20MHz+10MHz					
C-9	YES	(5+5)MHz/(10+10)MHz/(15+15)MHz	YES													5MHz+5MHz/10MHz+10MHz/15MHz+15MHz					
C-10	YES	(20+20)MHz	YES													20MHz+20MHz					
C-11	YES	(10+10)MHz	YES													10MHz+10MHz					
C-12	YES	(20+20)MHz/(20+20+20)MHz	YES													20MHz+20MHz					
C-13	TBD		TBD														TBD				
C-14	NO		YES													TBD	TBD	TBD	TBD		
C-15	YES	(15+15)MHz	TBD																		
C-16		(20+20)MHz	YES													(20+20)MHz					
C-17	YES	(5+5)MHz/(10+10)MHz														No					
C-18	Yes	(10+10)MHz, (20+10)Mhz																			
C-19	TBD		TBD																		

Table 11.CA survey results.

3GPP RAN4 and RAN5 are currently working to define requirements and tests for CA. DL CA is expected to be more commonly used, and work on DL CA is being prioritized over UL CA.

The simultaneous operation of multiple LTE carriers is in some ways similar to simultaneous multi-mode operation. Both cases require management of interference between the different radio bands.

For intra-band CA, or CA between bands in the same frequency range, a single RF Front-End Module (FEM) that covers all of the component carriers can be used for DL CA.

For inter-band CA, multiple FEMs may be required to support the different bands. The RFIC will need to be able to simultaneously work with the multiple FEMs. Simultaneous use of multiple FEMs requires management of power constraints and interference, and may increase the complexity of the RFIC.

Uplink CA has additional challenges beyond those for DL CA. Simultaneous transmission on multiple component carriers (CCs) would almost certainly break the contiguous RB property for SC-FDMA, increasing the MPR and making it more difficult for the UE to meet OOBE requirements. Even if simultaneous transmissions are not required and UL CA is used only for enhanced load balancing, wider bandwidth PAs (e.g. 40 MHz rather than 20 MHz) would be required, which could potentially increase costs.

Since current usage patterns lead to DL congestion more often than UL, UL CA may be less necessary than DL CA. As a result, initial implementations of Carrier Aggregation in UEs may support DL CA only, with UL CA support lagging for some time.

Finally, with asymmetrical CA, the impact of the Local Oscillator frequency must be considered. For a single carrier, the center DC subcarrier corresponds to the LO frequency, and is not allocated. For symmetrical CA, the center of the occupied bandwidth will be either in the inter-carrier gap (for even numbers of CCs) or in the center gap of one of the CCs (for odd numbers of CCs). However, for asymmetrical CA, the center of the occupied bandwidth may be a subcarrier that would normally by occupied in one of the CCs.

4.6.1 INTRA-BAND CA REQUIREMENTS

Most GTI members plan to support intra-band CA. Support for inter-band CA on the GTI core bands (38, 40, 41) is most common, but GTI members also plan support on Band 39 (~1900 MHz) and Band 42/43 (~3500 MHz).

Band	Low (MHz)	High (MHz)	Number Operators	Uplink CA?	Asymmetrical
38	2570	2620	4	Yes	Yes
39	1880	1920	1	No	No
40	2300	2400	5	Yes	Yes
41	2496	2690	5	Yes	Yes
42/43	3400	3800	1	Yes	No

Table 12.GTI intra-band CA requirements.

Members report plans for asymmetrical CA in the GTI core bands. In addition, GTI members plan to support UL CA in the core bands, and in Band 42/43. Furthermore, it must be emphasized that inter-band carrier aggregation is required for (20+20) MHz adjacent carriers, which simplifies device design as it has to deal with 40MHz of contiguous spectrum.

4.6.2 INTER-BAND CA REQUIREMENTS

GTI members plan to use inter-band CA across all the GTI core bands (38, 40, 41). At least one GTI member also plans to support CA between bands 40 and 42/43.

As part of multi-mode support, GTI members plan to support CA among various FDD bands, including bands 1, 2, 3, 4, and 7.

4.7 DEVICE CONFIGURATION REQUIREMENTS TO SUPPORT ROAMING SCENARIOS

UMTS roaming on traditional mobile networks is based on authentication against public land mobile network (PLMN) IDs (sometimes known as Operator IDs). A PLMN ID is unique to each operator and is a concatenation of the Mobile Country Code (MCC) and the Mobile Network Code (MNC).

The UE normally operates on its home PLMN (HPLMN) or equivalent home PLMN (EHPLMN). However a visited PLMN (VPLMN) may be selected, e.g., if the MS loses its home network connection. In this case, there are two modes for PLMN selection:

1. Automatic mode: This mode utilizes a list of PLMNs in priority order. The highest priority PLMN which is available and allowable is selected.
2. Manual mode: Here the MS indicates to the user which PLMNs are available. Only when the user makes a manual selection does the MS try to obtain normal service on the VPLMN.

There are two cases for roaming boundaries:

- International Roaming: This is where the MS receives service on a PLMN of a different country than that of the HPLMN.
- National Roaming: This is where the MS receives service from a PLMN of the same country as that of the HPLMN, either anywhere or on a regional basis. The MS makes a periodic search for the HPLMN while national roaming.

GTI is working on establishing a suitable roaming arrangement between members as soon as practicable. To this end, device USIMs could potentially be configured to facilitate preferred or prioritized roaming to a GTI partner before alternative networks. That is, PLMN-IDs for GTI members could be preconfigured with higher priority on the USIM based on business arrangements.

5 DEVICE ARCHITECURE RECOMENDATIONS

This section will focus on device architecture recommendations that would facilitate and enhance TD-LTE ecosystem and address device requirements as specified in the previous section. Furthermore, this section will highlight some of the most recent technological development that would allow for some of the challenges related to MMMB devices to be met in the short and long term.

5.1 DEVICE ARCHITECTURES

The focus of this paper is on global roaming devices, which mainly encompasses smartphone devices. However, as there are indications that other types of devices may have a global or regional appeal, GTI's MM-MB working group surveyed operators on all the types of devices they may require for their users. Table 13summarizes the results of that survey

Company	Device From Factor				
	SP	Tablet	HotSpot Router	USB/Data Card	CPE
C-1	√		√	√	
C-2	√	√	√	√	√
C-3	√	√	√	√	√
C-4	√	√	√		
C-5	√	√		√	
C-6			√	√	√
C-7	√	√	√	√	√
C-8	√	√	√	√	
C-9					
C-10				√	√
C-15	√		√	√	
C-11					
C-12	√	√	√	√	√
C-13	√	√	√	√	√
C-14	√				
C-15	√		√		√
C-16			√		
C-17			√	√	√
C-18	√		√	√	√

Table 13.Type of devices required by GTI operators.

Survey results clearly indicate that smartphones are the main global roaming device considered by the GTI operators at this stage. However, there is a growing interest on tablets and hotspot personal router devices to provide support for multi-band configurations so that those devices could be used for national, regional, and in some cases global purposes as well. GTI is currently conducting a more detailed survey dedicated to data only devices and the need for global configuration for such devices. The results of that survey and respective requirements will be published in a subsequent version of this paper.

As each of those device categories have different type of requirements in terms of multi-mode multi-band support and type of applications (i.e. data only-vs-voice and data) it is understandable that different device hardware architecture would be applicable for each specific type of device. However, as the level of functionality integration in a single chipset is constantly incremented, there is a lot of commonality between chipsets and RF electronic components that can be reused irrespective of device type. This should be considered a positive development as it would help reduce device cost due to economies of scale factor.

The following sub-sections describe some of the main architectures considered and recommended to implement GTI MM-MB requirements.

5.1.1 GLOBAL DEVICE ARCHITECTURES FOR SMARTPHONES

Smartphones are becoming more and more an indispensable tool to the lives of millions of their users not only as a mean of basic communication needs but for far more sophisticated usage thanks to the huge plethora of data applications supported by those devices. Therefore, it is not surprising to notice that GTI operators regard the smartphones as the main global device type for global roaming purposes. In order to support functionalities and requirements highlighted in Section 4, two different architectures should be considered based on a single or dual baseband chipset architecture. Sections below describe those architectures in more details.

5.1.1.1 SINGLE CHIPSET ARCHITECTURE

This architecture is based on the utilization of single baseband chipset capable of handling multiple core technologies like 2G/3G/4G. Figure 6 depicts a block diagram of such architecture.

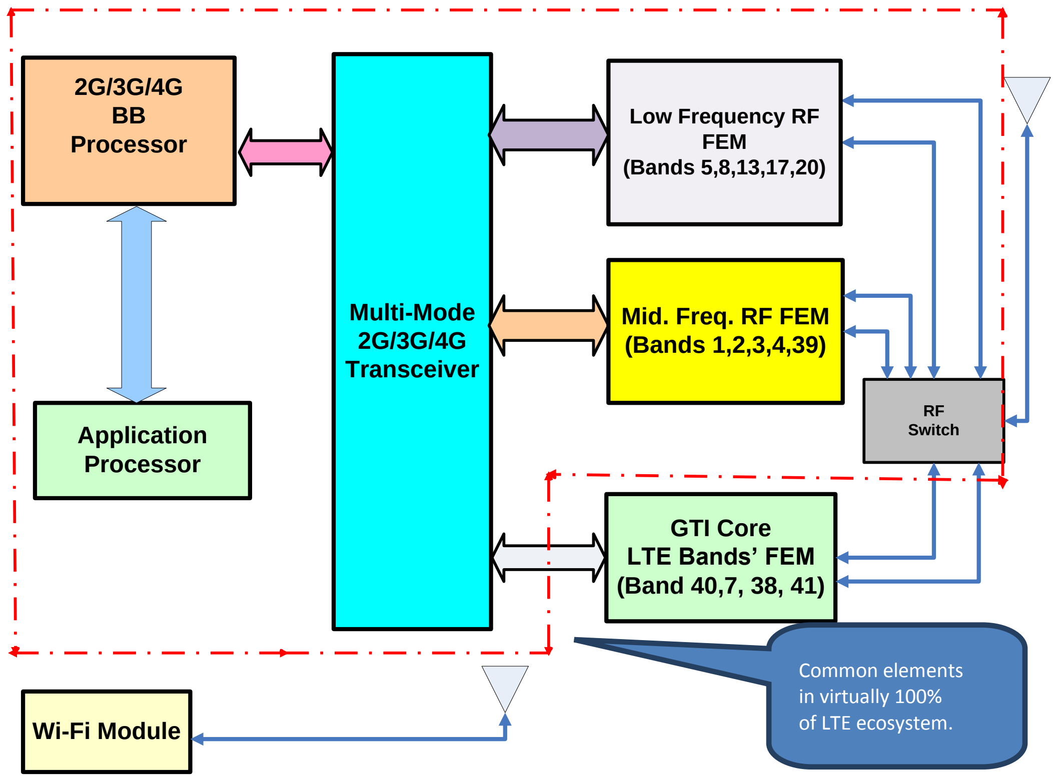

Figure 6.Single baseband smartphone architecture.

The main advantage of this architecture when compared with other options is its ability to provide for smaller device size, lower power consumption, and potentially lower cost. However, the advantage of a single complex multi-mode baseband processor brings certain additional challenges in terms of development and interoperability testing particularly in the introductory stages of a new technology.

It should be mentioned that device architectures required by GTI operators re-use to a very large extend the chipsets and electronic components that are part of the entire LTE ecosystem, hence not imposing any major additional requirements. As it is well known, both FDD and TDD modes of LTE share more than 90% of commonality in terms of 3GPP functionality. Therefore, all the work done to date in developing FDD LTE systems can almost apply entirely to TD-LTE devices. The only additional requirement would be in supporting 2.3-2.7GHz core LTE bands, which are new to the industry. While those bands represent certain technical challenges in terms addressing ISM co-existence and large bandwidths inherited by some of those bands, the recent technological advancements allow for effective and low cost solutions. GTI in co-operation with IWPC has established a working group to study and analyze optimal RF front-end architectures supporting 2.3-2.7GHz LTE bands (i.e. band 40,7,38, and 41) and the recommendation of that work are presented in the form of a white paper [9]. As that work indicated, 2.3-2.7GHz LTE bands can be supported very efficiently and with minimal impact on device size due to the frequency proximity of those bands. Furthermore, innovative designs described in [9] provide a very cost effective solution supporting those core GTI LTE bands, which cover more than 50% of world's population with potential customer base of more than one billion.

Baseband Processor:

The core of this architecture is the single baseband processor capable of supporting multi-mode technologies like 2G, 3G and 4G LTE. Such architecture offers the advantages of a smaller device size, reduced power consumption, as well as reduced bill of materials.

There are a number of tier one chipset manufacturers that support multi-mode technologies and could be good candidate for this architecture. Qualcomm's MSM8960 family of processors is a good example of such chipsets [ref]. Also, several tier 1 chipset manufacturers are coming up with multi-mode solutions, particularly supporting HSPA and LTE, that could be a good candidate to support such architecture. Therefore, there is a growing belief that this architecture would become the de-facto choice in the long-term for supporting multi-mode multi-band smartphone designs.

Application Processor:

Application processor is becoming an integral part of any smartphone design be it as a separate chipset or integrated with the baseband processor. In the case of LTE, which offers substantial increase in data traffic when compared to previous technologies, the performance of application processors will be a key consideration for any smartphone design. Several companies, such as Qualcomm, Samsung, Intel, Nvidia, etc, offer very powerful application processors with multi-core technology that will be able to handle LTE requirements.

Multi-mode Transceiver:

The need for a single transceiver, particularly in the case of CSFB required smartphones, is one of the key advantages of a single baseband chipset architecture. This would require that the transceiver supports frequencies from 700-2700MHz in order to support all GTI required bands.

In general, tier one baseband chipset vendors, which are very often known as device platform providers, offer their own transceiver chipsets. And such combination of baseband and transceiver from the same company facilities a lower integration burden to OEMs as everything has been previously proven to function properly in a reference design format provided by smartphone platform provider companies. The transceiver technology has progressed in recent years by integrated functionality that previously was present in RF front-end blocks, such as

LNAs and inter-stage SAW, hence allowing for smaller footprints and ease of component integration.

Also, it should be mentioned that several transceiver design companies offer very good and performing multi-mode multi-band chipsets that can be used in any combination with various baseband chipset solution. This interface is further facilitated by the use of open standard digital interface between baseband and transceivers, such as DigiRF etc.

RF Front End:

RF front-end subsystem consists of a combination of power amplifiers (i.e P.A), filters, duplexers, RF switches, resistors, capacitors, and inductors that provide for device conformance to 3GPP and national regulatory emission specifications. Figure 6 represents a logical partition of bands required in a multi-mode multi-band global smartphone device. It is understandable that various OEMs may combine RF front-end components in different grouping depending on component selection and functionality provided by those components. However, it should be mentioned that the integration of 2.3-2.7GHz RF front-end components into a single module/chipset is strongly recommended by GTI as an efficient way to facilitate device development. Readers are encouraged to consult [9] for a detailed analysis of such solutions and benefits associated with it.

5.1.1.2 DUAL STANDBY ARCHITECTURE

The main difference between this architecture and the one described in section 5.1.1.1 is the simultaneous handling of multi-mode 2/3/4G technologies through single / multiple baseband chipset. While this architecture provides simultaneous support for 2/3G and LTE, it comes with extra burden of requiring a larger device space and higher power consumption. Figure 7 shows a typical multi-mode multi-band device architecture that could be used for meeting GTI global roaming device requirements.

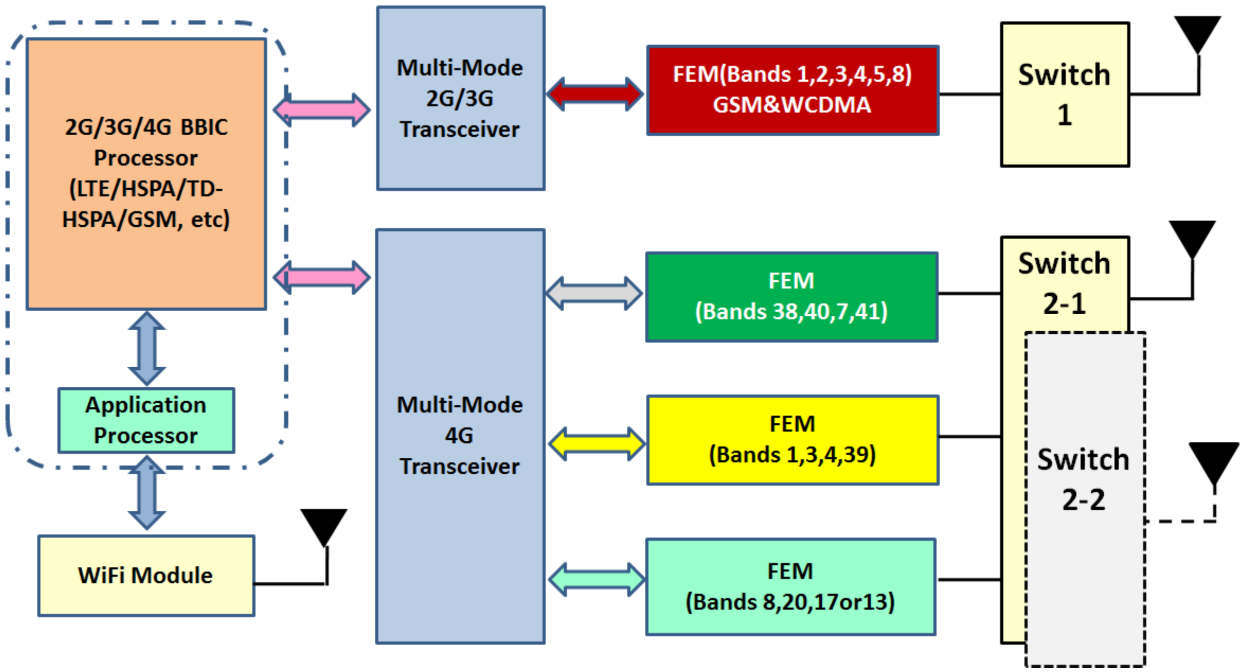

Figure 7.A typical dual standby multi-mode multi-band device architecture.

In this example, same baseband processor and multiple transceivers are required to simultaneously support 4G and 2/3G technologies. It should be mentioned that other functionality partition on baseband processors is possible. For instance, 3G and LTE could be part of a single processor while 2G is addressed by a separate processor. Also, the application processor may well be integrated as part of a 2/3G baseband processor, hence the blue dotted line in Figure 7. Also, in some cases, the transceiver and the baseband processor could be integrated in a single chipset. More information about these architecture designs is presented in Appendix I.

This architecture can support both CSFB and dual standby mode in an effective manner although at a cost of extra complexity. While this complexity and extra cost is well understood in the industry, it should be mentioned that the smartphones using such designs have progressed significantly in the last years, particularly at initial stages of new technology introduction. Some of those designs have taken advantage of integration of 4G baseband and transceivers into a single module/chipset, hence reducing size and lowering power consumption.

It is well known that to date the majority of current 4G smartphone designs in the USA are based on dual standby design, and some models proved to be the all-time best selling devices for those operators.

Figure 8 depicts some of those models available in market today.

Figure 8.Various dual-chipset 4G smartphone used currently in the US market.

5.1.2 DATA ONLY DEVICE ARCHITECTURES

As Table 13 indicates, GTI operators have shown significant interest for data only devices. Therefore, GTI intends to benefit by sharing from common data cards/CPE/Hotspot Routers device architecture by utilizing common parts with smartphone designs and designated OEMs in order to reduce device costs and expedite device development process. The following subsections describe architectures recommended for those types of devices.

As mentioned above, GTI is currently conducting a more detailed survey for data only devices and the need for global configuration for such devices. The architectures presented in this paper reflect the current status of survey results, which should still be valid for future any enhancement.

5.1.2.1 MULTI-MODE MULTI-BAND ARCHITECTURE FOR MOBILE HOTSPOTS

Multi-Mode hotspot router devices would reuse to a large extends parts and components used for smartphone devices. Differences between smartphones and personal mobile hotspot devices are mainly on application processor, which generally is not present on a mobile hotspot device, and on RF front-end part. Generally, mobile hotspots are less complex of RF front–end solutions when designed per a specific market. This is mainly due to the fact that not all band combinations required on global smartphone devices would be required for mobile personal hotspot devices. However, as the interest in data roaming solidifies, it is foreseen that there will be less and less differences between a global roaming smartphone and mobile personal hotspot on RF front-end solutions and band support.

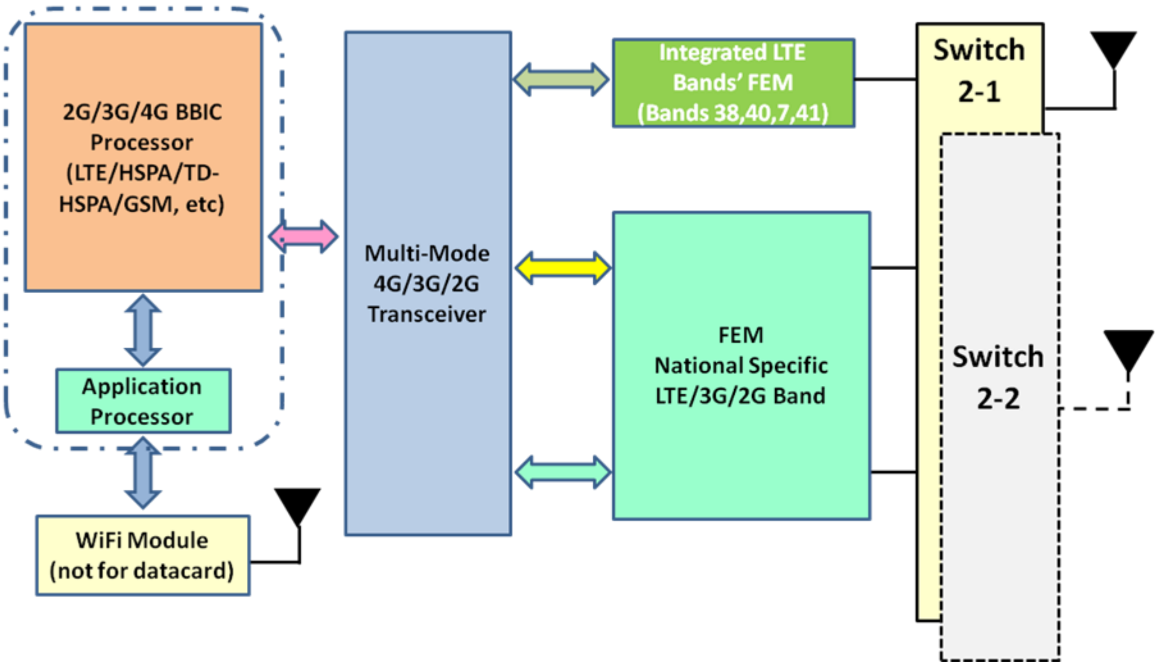

Figure 9. A typical personal hotspot device architecture addressing GTI needs.

Figure 9 depicts the case of an architecture supported with a single multi-mode baseband chipset, although there is no reason why a dual-chipset baseband solution could not also be used. Obviously, some of the shortcomings associated with such design and highlighted in the case of smartphone architectures described in Section 5.1.1.2 would still apply in this case.

The thrust of those devices is built around the support for 2.3-2.7GHz bands, which constitute the core of GTI LTE bands and cover more than one billion customers in addition to a particular national or regional band required by a certain operator. It is believed that this combination would benefit from the economies of scale related to 2.3-2.7GHz bands and allow this type of device to cross the boundaries of a single nation and be used for global roaming users as well.

Furthermore, there may be certain markets where activation of 2G technologies for such devices may be required. Such functionality could be easily supported with the architecture shown in 错误！未找到引用源。, as multi-mode multi-band 3/4G chipsets do also support 2G. However, in this case, RF front-end needs to provide support for 2G bands.

5.1.2.2 ARCHITECTURE FOR DATA CARDS / CPE

GTI is currently composed of more than 34 operators. As Table 12 shows, a large number of GTI operators require support for CPE devices, particularly with support for 2.3-2.7GHz bands. This is the case for several operators in developing countries in South Asia. Therefore, all the work done for providing an integrated RF front-end solution supporting 2.3-2.7GHz bands for smartphone devices could be re-used for those devices as well. A typical CPE LTE device architecture could be very similar to that shown in 错误！未找到引用源。, but with a different transmit power level (i.e. portable devices are usually limited to 23dBm whereas CPEs could use 27dBm or higher depending on their user case) . Furthermore, CPEs could use a more restricted number of RF bands, as they are not necessarily meant for global roaming deployments. In addition, there may be cases when CPE devices are required to only support LTE technology. Therefore, for such cases, there may not be a need for multi-mode support, hence those devices could use a dedicated FDD/TD-LE chipset in order to reduce cost and integration complexity rather than a multi-mode chipset.

Furthermore, LTE USB dongle / data cards could use the same architecture, but without the need for Wi-Fi or application processor support as these functionality are already embedded in laptop/netbook devices.

5.1.2.3 TABLETS –A NEW AREA ON DATA DEVICES

Tablets have the potential to become one of the most successful mobile device categories with sale forecasts expected to reach 261.4M by 2016 [12]. GTI operators are very keen on adding those types of devices into their device portfolio. Projections suggest that around 30% of tablets will be supporting WWAN, number which could be higher if WWAN comes with a lower cost and flexible offering from carriers.

A tabled device OEM could opt for a comprehensive solution by supporting the entire, or a subset, of RF bands shown in Table 8. Figure 10 shows a potential architecture for such configuration.

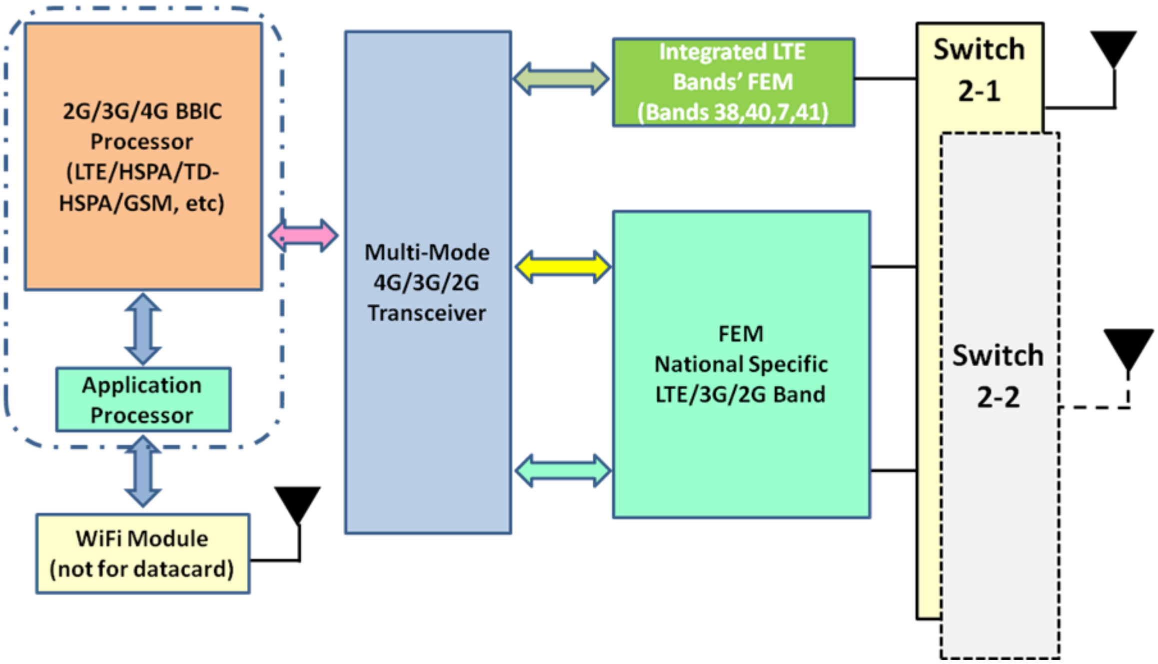

Figure 10. Generic 2/3/4G modem architecture for a tablet design.

However, in the context of tablets, the proximity between 2.3-2.7GHz LTE bands and Wi-Fi frequencies (i.e. 2.4-2.48GHz) may provide a significant advantage in reducing the wireless modem cost included in those devices as shown in Figure 11

In this particular architecture, the reduction in cost would come from reduced complexity of a single transceiver serving only 2.3-2.7GHz, integrated RF front end between Wi-Fi and 2.3-2.7GHz LTE bands, and potentially integrating LTE+ Wi-Fi baseband processors. There are indications that some next generation LTE baseband chipsets would come with embedded support for Wi-Fi technology, and such integration becomes much easier in the case of LTE and Wi-Fi as both technologies are OFDM based and not operating concurrently in tablet device.

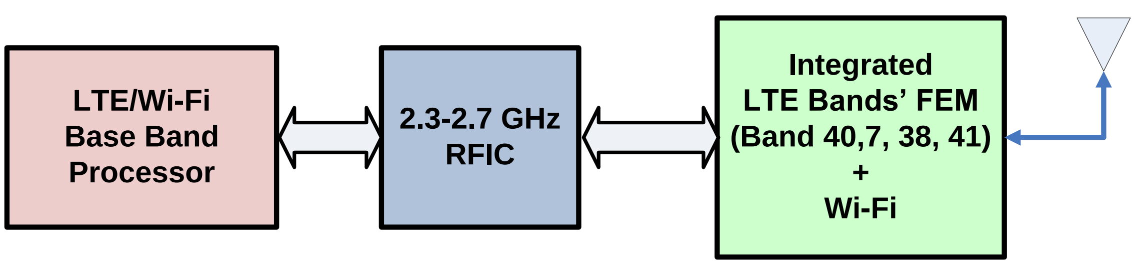

Figure 11. A wireless model architecture supporting 2.3-2.7GHz LTE bands and Wi-Fi technology.

6 CONCLUSION

Having surveyed GTI member companies on their TD-LTE multi-band, multi-mode device design requirements to address immediate network deployment needs as well as longer range deployment plans, the MMMB task force identified a common set of frequency bands, 2G/3G technologies and other capabilities that should be supported in initial device designs – both smart phones as well as data-centric devices - to meet the near-term requirements of the majority of GTI member companies.

The recommended smart phone design includes thirteen different frequency bands, relying on the 2.3-2.7 GHz range as the backbone, to support global roaming. Along with the combination of FDD LTE and TD-LTE, HSPA and 2G technologies, this device design will facilitate coverage to a customer base of more than one billion people, which represents 60% of world's population. The MMMB task force also recommends that the device design include support for LTE Release 9 as well as full support for hand-off between the two LTE variations (FDD and TDD) with all MIMO transmission modes. Additional data-centric device designs should leverage the RF front end development work for smart phones to maximize efficiencies and expedite the development process.

With this set of common requirements identified, GTI will commence working closely with OEM and other ecosystem partners to bring devices incorporating these design criteria to market as expeditiously as possible.

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8 APPENDIX - I

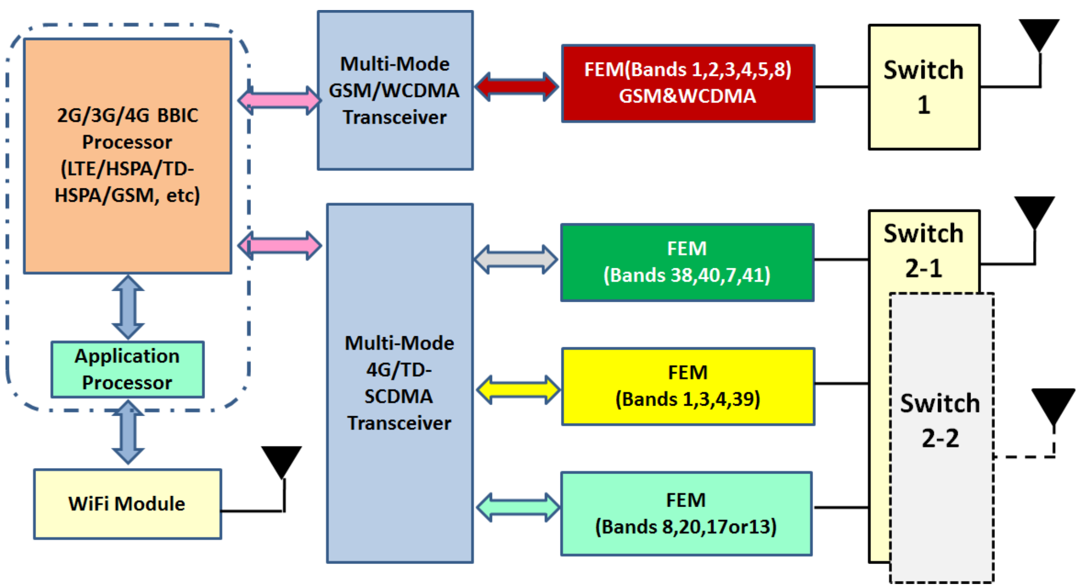
This section provides additional variance of dual stand-by and single stand-by architectures for the completeness of the whitepaper.

8.1 ADDITIONAL DUAL STANDBY ARCHITECTURES – SINGLE BBIC SOLUTION

Single base-band dual-standby architecture implementation may vary depending on a variety of factors, where the connectivity and functionality partition between the BB processor and RF transceivers is a key determining factor. Subsections below depict various partition and connectivity designs related to such implementation.

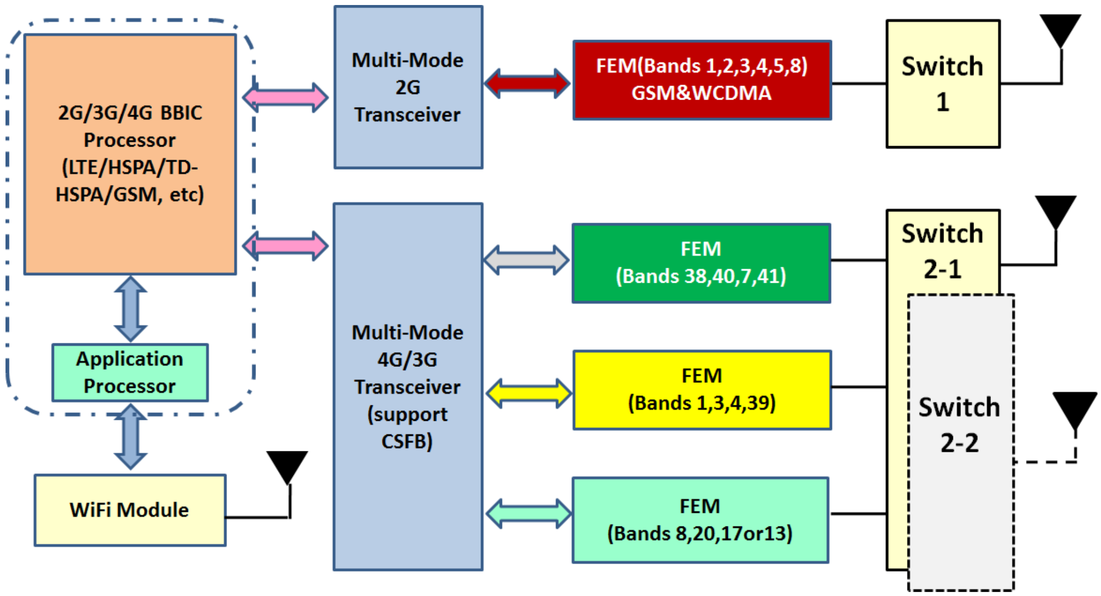
8.1.1 LTE / TD-SCDMA + WCDMA / GSM

In this example, a single baseband processor and separate transceivers and RF switches are required to support 4G / TD-SCDMA and GSM/WCDMA technologies. Also, the application processor may be integrated as a part of main BBIC processor.



8.1.2 LTE / TD-SCDMA / WCDMA + GSM

In this example, a single baseband processor and separate transceivers and RF switches are required to support 4G / 3G and 2G technologies. Also, the application processor may be integrated as a part of main BBIC processor.

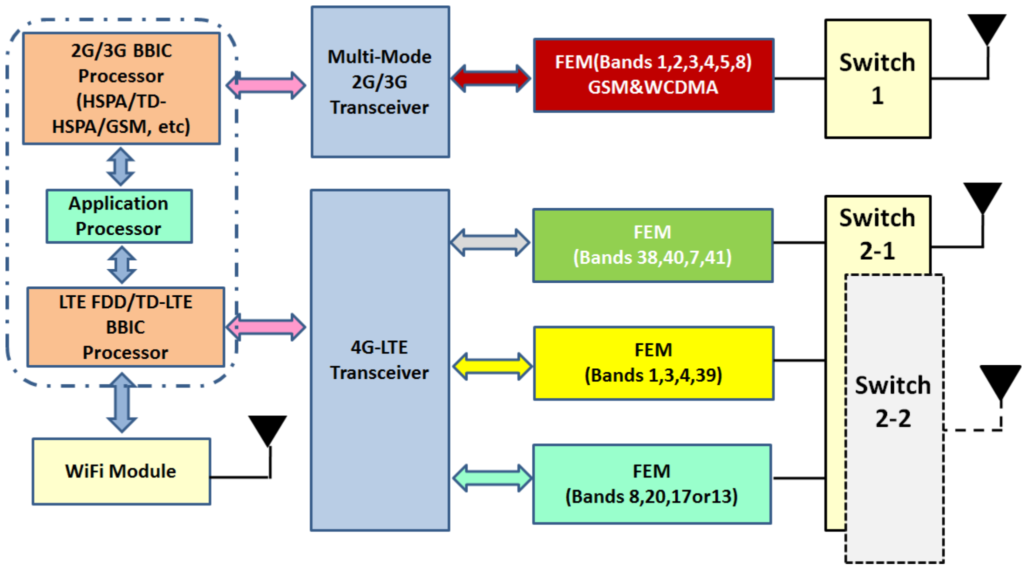


8.2 ADDITIONAL DUAL STANDBY ARCHITECTURES – DUAL BBIC SOLUTION

Dual base-band standby architectures vary in their design implementation mainly on the partition of functionality between used BB processors and their interfaces to RF transceivers. The support for a particular 2/3G technology may also dictate such partition and design implementation. Sub-sections below show some examples of such implementations.

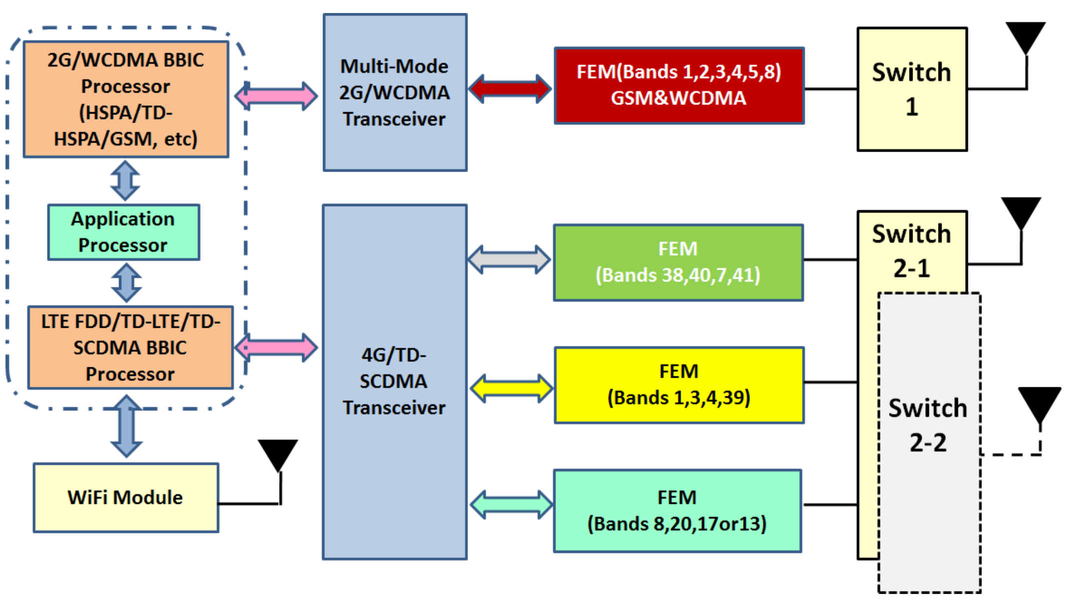
8.2.1 LTE + WCDMA / TD-SCDMA / GSM

In this example, a separate baseband processor and transceiver may be required to support 4G technologies while 2/3G technology is addressed through a separate solution.



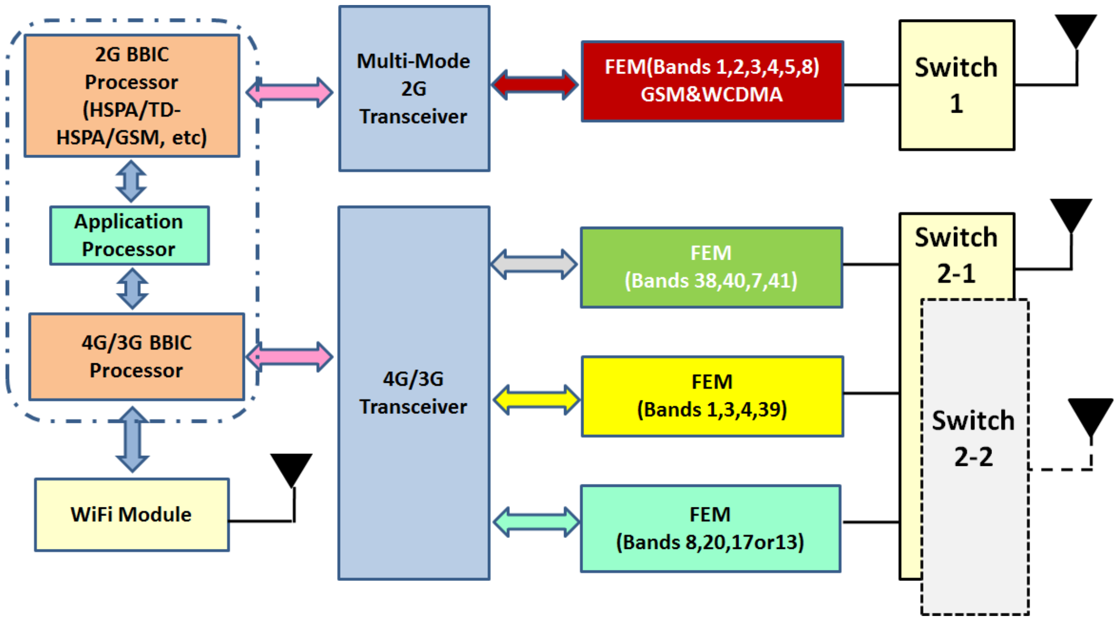
8.2.2 LTE / TD-SCDMA + WCDMA / GSM

In this example, a separate baseband processor and transceiver may be required to support 4G/TD-SCDMA technologies while 2G/WCDMA technology is addressed through a separate solution.



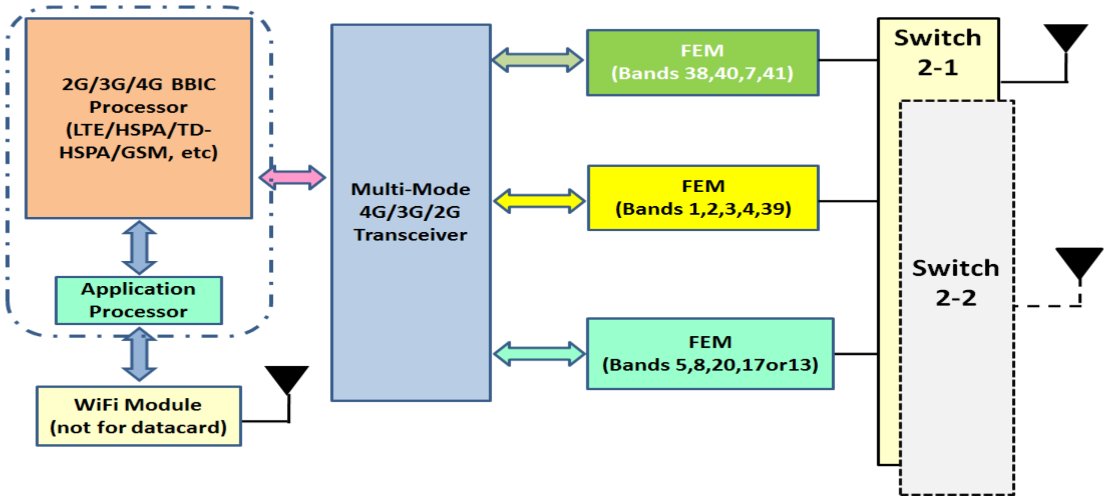
8.2.3 LTE / TD-SCDMA / WCDMA + GSM

In this example, a separate baseband processor and transceiver may be required to support 4G / 3G technologies while 2G technology is addressed through a separate solution.



8.3 ADDITIONAL SINGLE STANDBY ARCHITECTURE

Section 5.1.1.1 described a smartphone architecture which his based on the use of a single antenna system. However, there are other alternative solutions two or more antennas can be used to cover the entire RF frequency bands supported by the device. Figure below depicts such a case.


2G/3G/4G BBIC
Processor
(LTE/HSPA/TD-
HSPA/GSM, etc)
Application
Processor
WiFi Module
(not for datacard)
Multi-Mode
4G/3G/2G
Transceiver
FEM
(Bands 38,40,7,41)
FEM
(Bands 1,2,3,4,39)
FEM
(Bands 5,8,20,17or13)
Switch
2-1
Switch
2-2