Bolero Wireless Communications and DECT RF Environments

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Introduction

Today's productions require ever increasing quantities of wireless communications and associated intercom beltpacks as production teams push for higher mobility and greater degrees of flexibility across venues. With increasing numbers of users in the same RF space, plus multiple production teams from different companies, the need to understand overall system capacity and potential limits becomes a critical risk analysis exercise.
This paper describes how both single and multiple DECT-based wireless systems work, scale, coexist or potentially conflict in today's production environments.

What is DECT?

The term DECT stands for Digital Enhanced Cordless Telecommunications. It is a near global license free ETSI standard for bi-directional wireless communications operating nominally in the 1.9GHz frequency range, which provides a good combination of range and material penetration while minimising absorption effects seen at higher frequencies. DECT frequencies vary depending on the particular country or region as generally summarised below:

Figure 1: DECT Frequencies and Power in Different Geographic Regions

Region	Peak Power mW	DECT Frequency Range (MHz)	Carrier Band (MHz)	No of Carriers	No of Useable Timeslots
Europe	250mW peak, 10 mW avg	1880 - 1900	20	10	100
North America	100mW peak, 4 mW avg	1920 - 1930	10	5	50
Australia	250mW peak, 10 mW avg	1880 - 1900	20	10	100
Japan	100mW peak, 4 mW avg	1894 - 1906	12	6	30 to 60 (shared with PHS)
Brazil	250mW peak, 10 mW avg	1910 - 1920	10	5	50
Latin America	250mW peak, 10 mW avg	1910 - 1930	20	10	100
Middle East	250mW peak, 10 mW avg	1880 - 1900	20	10	100
South Africa	250mW peak, 10 mW avg	1880 - 1900	20	10	100

The above frequency allocations result in essentially two DECT capacities: 100 useable timeslots for 10 carrier environments and 50 useable timeslots for 5 carrier environments. The number of timeslots in combination with the type of scheme used (e.g. single slot or dual slot transmission) can therefore be used to give an initial indication of the system capacity.

DECT Wireless Communications Systems

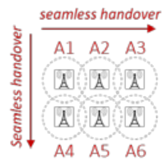
DECT devices can be a single-device to access point (or basestation) such as a cordless DECT phone or a multi-device to multiple access point system more typical of high-end intercom systems. In high-end intercom systems devices are typically referred to as beltpacks and access points (basestations) are more commonly referred to as antennas. This White Paper will focus on multi-device/multiple access point high-end intercom systems.

Seamless Handover Versus Roaming

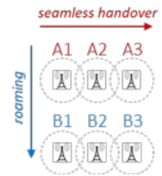
A typical production environment requires users to move freely around a stage, studio, stadium, racetrack or facility. This requires systems that are typically built up of a number of antennas (access points) with beltpacks able to move from antenna to antenna, analogous to a mobile phone cellular network.

Two main mechanisms exist in order to support this requirement, depending on the system in question; seamless handover mechanisms and roaming mechanisms.

Seamless handover based networks synchronise the entire antenna network enabling beltpacks to automatically move between antennas without interruption of audio. This is just like a cell phone moving between various cell towers when you drive your car from town to town within the same mobile network. These are highly advantageous in production environments as they allow the free movement of personnel without the need for manual intervention.



Roaming based networks allow beltpacks to cross from one antenna or network to another but not seamlessly i.e. there is an interruption in audio. This is analogous to a mobile/cell phone moving from state to state or country to country where the mobile phone switches from one mobile carrier to another mobile carrier.

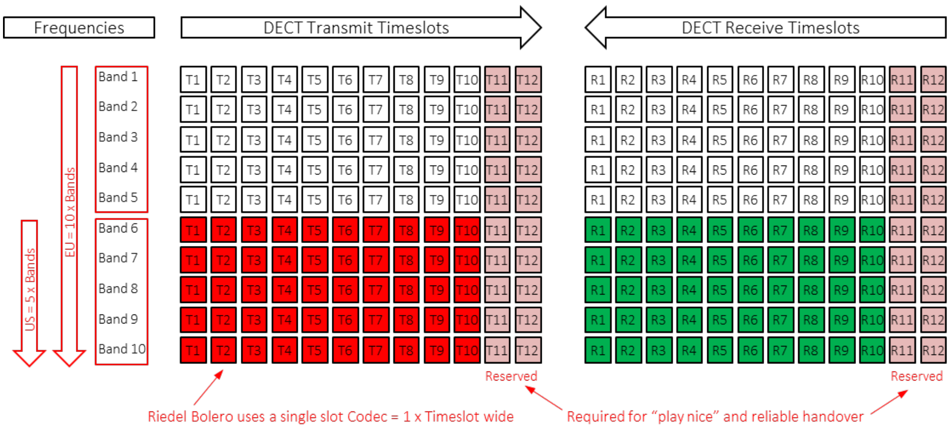


Single Slot versus Dual Slot Systems

DECT intercom systems can typically be divided into two classes, namely single slot and dual slot schemes. A single slot scheme uses one pair of bi-directional timeslots per communications channel (one for transmit and one for receive), whereas a dual slot scheme uses two pairs of bi-directional timeslots per communications channel. In dual slot schemes the timeslots are adjacent to one another.

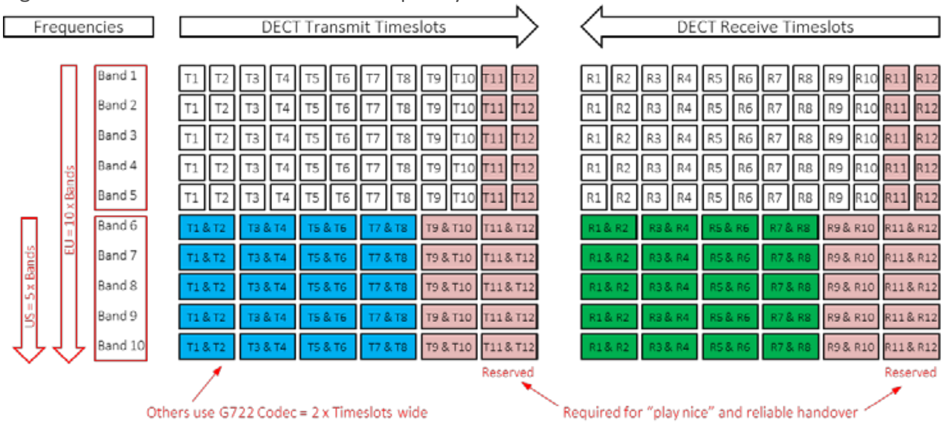
The two approaches are shown in the following diagrams:

Figure 2: Single Slot Scheme with Five Frequency Bands (bands 6 to 10 e.g. North America or Brazil)



In the above diagram 50 wireless beltpacks are represented by the Red squares. In order for DECT devices to “play nicely” together the DECT standard requires devices to regularly “hop” across frequency bands and timeslots. This mechanism enables any given device to select a timeslot with a better power budget and avoids any given device from sticking or “hogging” a particular frequency or timeslot which would prevent other devices from being able to access the spectrum. Movement of devices across frequency bands and timeslots happens in the order of ten milliseconds.

Figure 3: Dual Slot Scheme with Five Frequency Bands



In dual slot schemes the mechanism is essentially the same, the main difference being that the two adjacent timeslots must hop in a pair together. In the above diagram 20 beltpacks are represented by the Blue squares.

Dual slot mechanisms were originally developed to overcome codec limitations that limited audio bandwidth of the comms channel to 3.5KHz. The advent of dual slot schemes allowed codecs such as G722 to be implemented increasing audio bandwidth to 7KHz, providing much higher levels of quality and intelligibility. Dual slot schemes traditionally have the advantage to double audio bandwidth, but with a corresponding disadvantage that they halve the overall available capacity. This is due to the fact that they consume double the number of timeslots for the same number of devices compared to a single slot based system. Modern codecs, however, can achieve higher audio performance while only requiring a single timeslot.

Another downside of dual slot systems is that they require two freely available adjacent timeslots in order for a device to be able to move or “hop”. As DECT devices will only move to “clean” timeslots (i.e. timeslots that do not have interference due to either competing DECT devices or frame errors/bit errors caused my RF multipath reflections) dual slot schemes potentially have a much lower probability of a successful hop statistically speaking. This problem becomes compounded as the number of devices in an overlapping RF space increases and available timeslot capacity reduces.

Capacity in a Pure DECT Environment

A pure DECT environment is one where only a single manufacturers DECT-based devices exist i.e. there are no other third party devices such as cordless phones or other DECT-based intercom systems operating.

There are five key elements that affect the overall capacity of a system:

- The number of frequency bands in a given geographic region
- The number of antennas in the system
- The RF (Radio Frequency) overlap of antennas
- Maximum antenna count per given area
- Interference

These elements are addressed in the following sections.

Number of Frequency Bands in a Given Geographic Region

As shown in Figure 1 the world can basically be divided into two groups; ten frequency band regions and five frequency band regions.

A **ten frequency band** region, for example Europe, Australia, Middle East has ten frequency bands with ten useable timeslots per band. This gives the following basic capacity limits:

- Single slot: 100 bi-directional timeslots which equals a system capacity of 100 beltpacks
- Dual slot: 50 bi-directional timeslots which equals a system capacity of 40 beltpacks (10 beltpack capacity is lost due to the double timeslot reserved for handover)

A **five frequency band** region, for example, USA, Canada, Brazil, has five frequency bands with ten timeslots per band. This gives the following a basic capacity limits:

- Single slot: 50 bi-directional timeslots which equals a system capacity of 50 beltpacks.
- Dual slot: 25 bi-directional timeslots which equals a system capacity of 20 beltpacks (5 beltpack capacity is lost due to the double timeslot reserved for handover)

Note that the timeslot table in Figure 3 shows twelve timeslots per band giving a theoretical upper limit of 120 timeslots for Europe and 60 timeslots for North America, however, two timeslots per band need to be reserved in order to enable system management and intracell handover data required for a seamless handover system, therefore the maximum useable upper limit is 100 useable timeslots (beltpacks) or 40 useable timeslots (beltpacks) in North America or other 5 band regions.

Number of Antennas in a System

In order to explain antenna count in an area, a single slot system will be used as an example e.g. Riedel's Bolero. This example assumes the system, is limited by RF space not network/design capacity and that a seamless handover mechanism is used rather than roaming.

Each antenna supports a capacity of up to 10 beltpacks while still allowing seamless handover of beltpacks to other antennas in the network. Capacity can therefore be calculated as 10x the number of antennas up to the maximum timeslot limit of the region e.g. 100 or 50. So for a 100 timeslot region, a minimum of 10 antennas are required to support 100 beltpacks. For a 50 timeslot region, the minimum number of antennas required to support 50 beltpacks would be 5.

Depending on the coverage required, more antennas can be added either to increase beltpack density in a given area or to extend the range a beltpack can cover. By building a chain of antennas, beltpacks can seamlessly handover across the antenna network. This is shown in the following diagram:

Figure 4: Multiple Areas with Seamless Handover

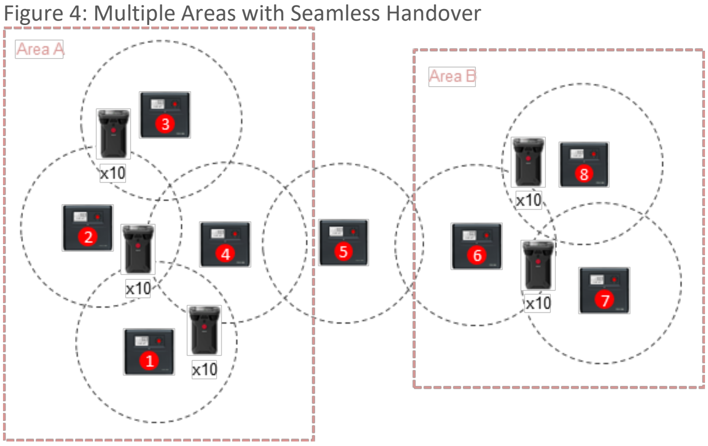


Figure 4 above shows two areas, Area A and Area B. Area A has 30 beltacks distributed across four antennas (one antenna is used for spare capacity) and Area B has 20 beltpacks distributed across three antennas (plus one antenna for spare capacity). The beltpacks can freely move between antennas they can “see” so in Area A they can freely move between the antennas that overlap and to the edges of each antennas coverage area (approximately 100 to 150 metre radius depending on the environment and building construction materials).

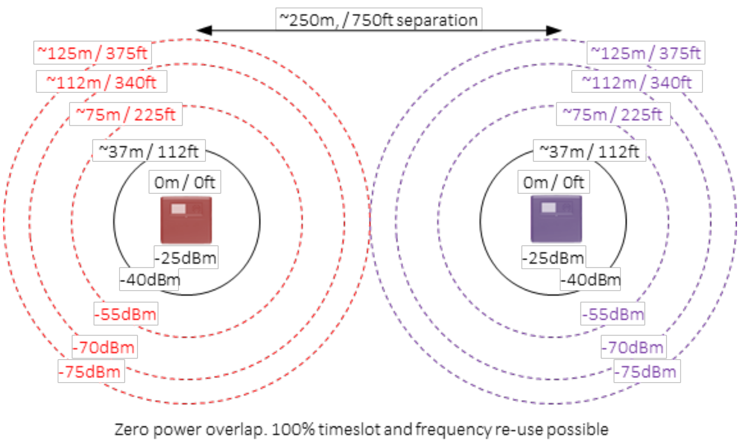
10 beltpacks can also freely move between Area A and Area B using antenna #5 as a bridge between the areas. If more than 10 beltpacks need to move between areas A and B an additional antenna could be positioned near antenna #5 to double the capacity in this area therefore providing a wider bridge between the areas.
In this example a 50 beltpack system has been created. In a five frequency band region one would expect this system to represent the maximum allowable capacity, however, this is not necessarily the case as the maximum capacity/density depends on the RF power overlap of the antennas as explained in the following section.

RF Overlap of Antennas

Again using Bolero as an example, a Bolero antenna has a range (radius) of approximately 150 metres / 450 feet in a typical line of sight application. This equates to a power range of approximately -23dBm at the antenna decreasing to a power level of ~-75dBm at the edge of the antenna’s range. At around -75dBm to -80dBm the system will look to handover beltpacks to other antennas with a better power budget in order to avoid loss of connection or poor quality audio artefacts.

This power/range number will vary depending on a variety of conditions including interference, building materials etc as well as antenna mounting height. For example, antennas mounted lower than head height will suffer from higher levels of attenuation caused by people in the work environment and will, therefore have a shorter range. Figure 5 below shows approximate distances versus power levels as a general guide.

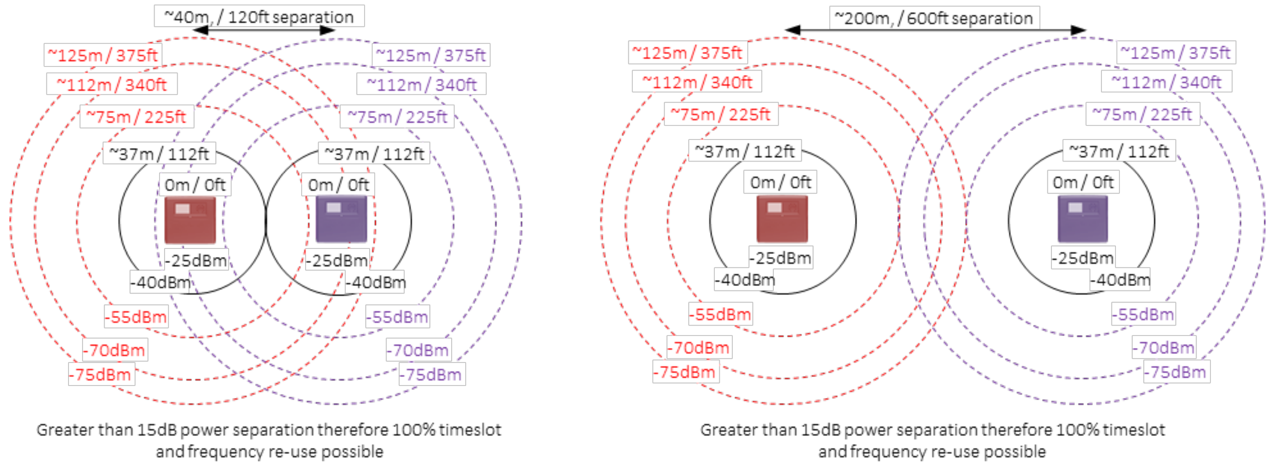
Figure 5: Bolero Antenna Power and Approximate Range



A little known but important characteristic of DECT is the ability of antennas to re-use the same frequency bands and timeslots once there is a certain power delta between antennas. In figure 5 above, the left antenna (Red) and right antenna (Purple) have zero power overlap which means they are both able to use exactly the same frequencies and timeslots without interfering with one another or consuming one another’s capacity. Seamless handover will not work at the two antennas are effectively isolated from one another.

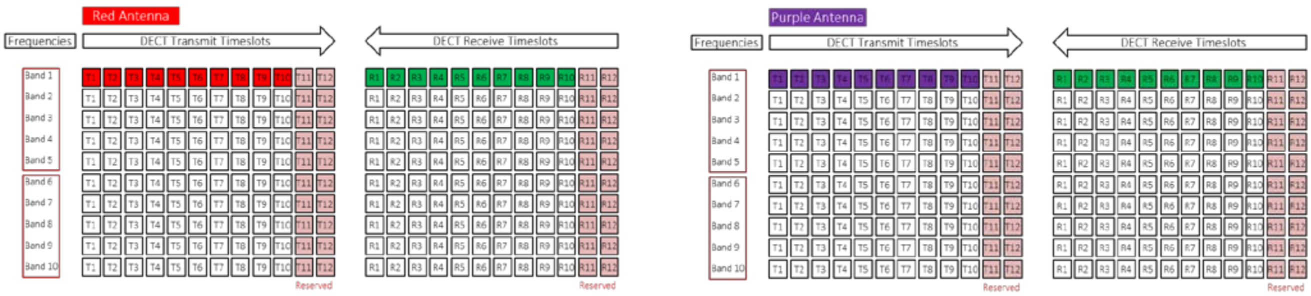
As antennas are moved closer together they start to overlap in the RF domain and seamless handover can occur. This is shown in Figure 6 below:

Figure 6: Partially Overlapping Antennas



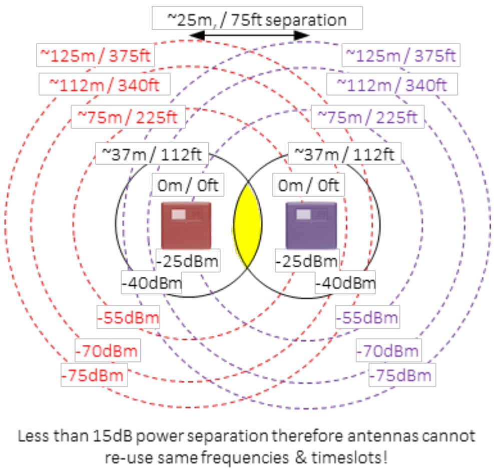
In these two examples the power delta reduces (power separation reduces) as the antennas are moved closer together. The magic number is approximately 15dB of power separation i.e. if the power separation of the antennas is greater than 15dB they will not interfere with one another.
This can be shown on the overall timeslot map as follows:

Figure:7 Partially Overlapping Systems Timeslot Consumption



It can be seen that both the Red and the Purple antennas overlap but have greater than 15dB of power separation. This means they can both use the same timeslots on the same carrier allowing two 100 beltpack (10 band region) systems to be implemented.
Once the antennas are separated by a power differential of less than 15dB they are considered to be a “100% overlapping RF space” which means they both consume timeslots out of the same maximum available timeslot budget.

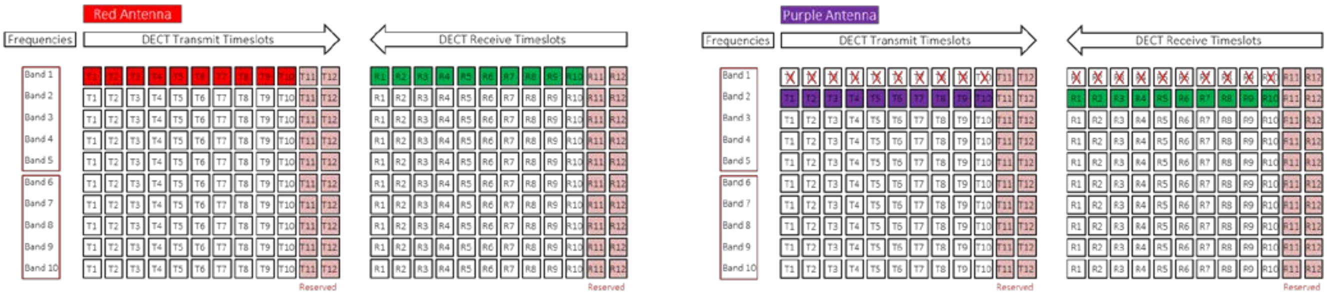
This is shown in the following diagram:
Figure 8: 100% Overlapping Antennas approximately 40m / 120 ft apart



In figure 8 we can see that the antennas are placed approximately 25 metres apart and therefore have a power separation of less than 15dB i.e. they can see a significant amount of each other's RF power (considered to be 100% overlapping). This is shown by the Yellow overlap area above. This means they will have to avoid each other's frequencies and timeslots and only use other available frequencies and timeslots.

For example, two antennas mounted next to each other would still coexist but if fully loaded with 10x beltpacks each would consume 20x timeslots of the available RF capacity. This is shown in the timeslot map in Figure 9.

Figure 9: 100% Overlapping Antennas Timeslot Consumption

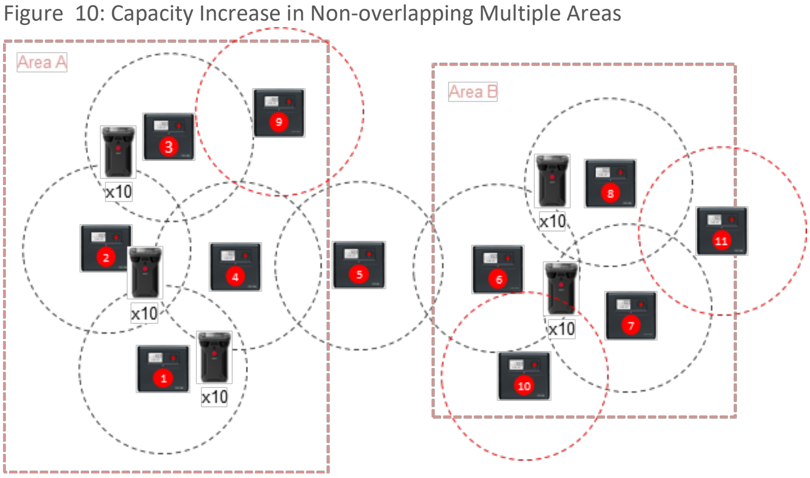


In the Bolero System, each antenna can "see" all frequency bands, timeslots and other Bolero antennas synchronised to the same Bolero NET and are therefore able to automatically handle this real time, dynamic frequency and timeslot management without user intervention.

In a typical install, it is uncommon to mount all antennas right next to each other as an antenna typically has a range of between 150 to 200 metres depending on the particular environment, so antennas are usually positioned to give the best combination of density and area coverage in a given space. Careful antenna positioning using these considerations can therefore allow effective system capacity to increase.

If we now take a second look at Area A and Area B again (shown in Figure 4), we can see that Area A and Area B do not overlap at all as shown below in Figure 10:

Figure 10: Capacity Increase in Non-overlapping Multiple Areas



This means they can coexist with exactly the same frequencies and timeslots which means there is potentially spare capacity for expansion of the system in both areas. Antennas 9, 10 and 11 can be added with zero impact adding either an additional 30x beltpacks or extra handover coverage. A distributed chain of antennas therefore, could continue adding capacity across a venue, campus, etc up to the current Bolero limit of 100x antennas, 100x beltpacks per Bolero NET.

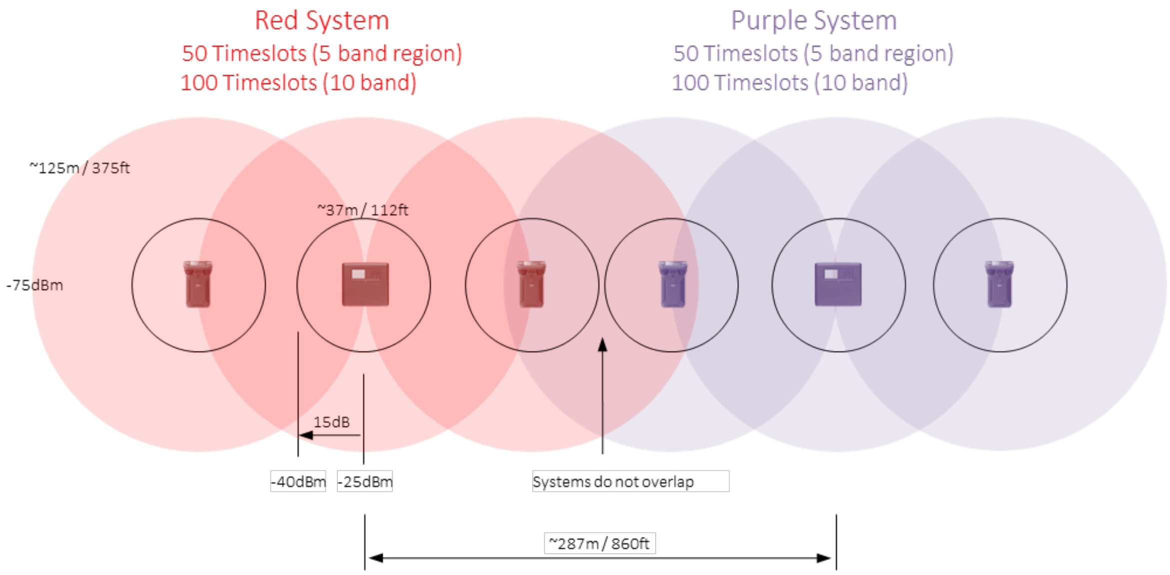
Maximum Antenna Count Per Area

Another way of looking at this is the total antenna count allowed per 100% overlapping RF space (i.e. less than 15dB of power separation between antennas).
In this scenario, a Bolero antenna will use 2x timeslots to “see” the rest of the Bolero network (with or without beltpacks). So in the worst case scenario of 100% antenna power overlap, the maximum number of antennas would be 50x antennas in a 10 frequency band region or 25x antennas in a 5 frequency band region.
These figures can be used as a general guideline for the maximum capacity in a given area. Again, by spacing antennas apart, more capacity can be added or safety margin added for other DECT systems to operate.

Impact of Beltpacks on Antenna Spacing

As previously stated, the typical range (radius) of a beltpack to antenna is approximately 125 to 150 metres or 375 to 450 feet. As each beltpack is tied to an antenna via a frequency band and timeslot (at any given time) the beltpack effectively extends the coverage or potential power overlap of the system. This is shown in the diagram below:

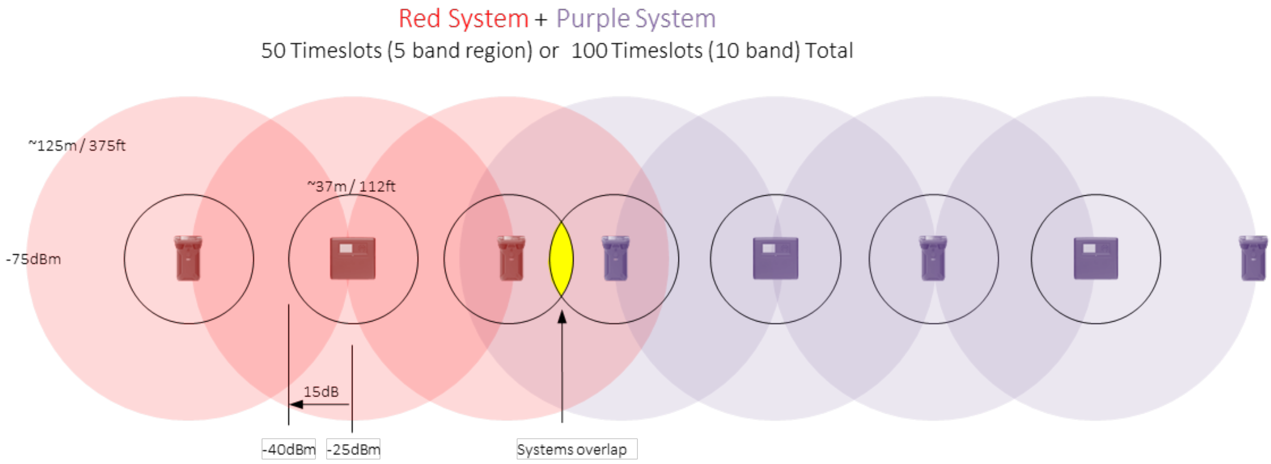
Figure 11: Antenna Separation Relative to Beltpacks at Edge of Range



In the above scenario, System 1 (Red) beltpacks are at the edge of their antenna range as are the System 2 (Purple) beltpacks. In this case the antennas are separated so that there is always more than a 15dB power separation i.e. the Black guardband rings (15dB) from one system never touch the Black guard band rings from the other system. This allows for two 100 timeslot systems to be operated without interference with one another but requires a significant separation of the antennas.

In Figure 12 below the Red System and the purple System now overlap due to the beltpacks extending the antenna range or interaction:

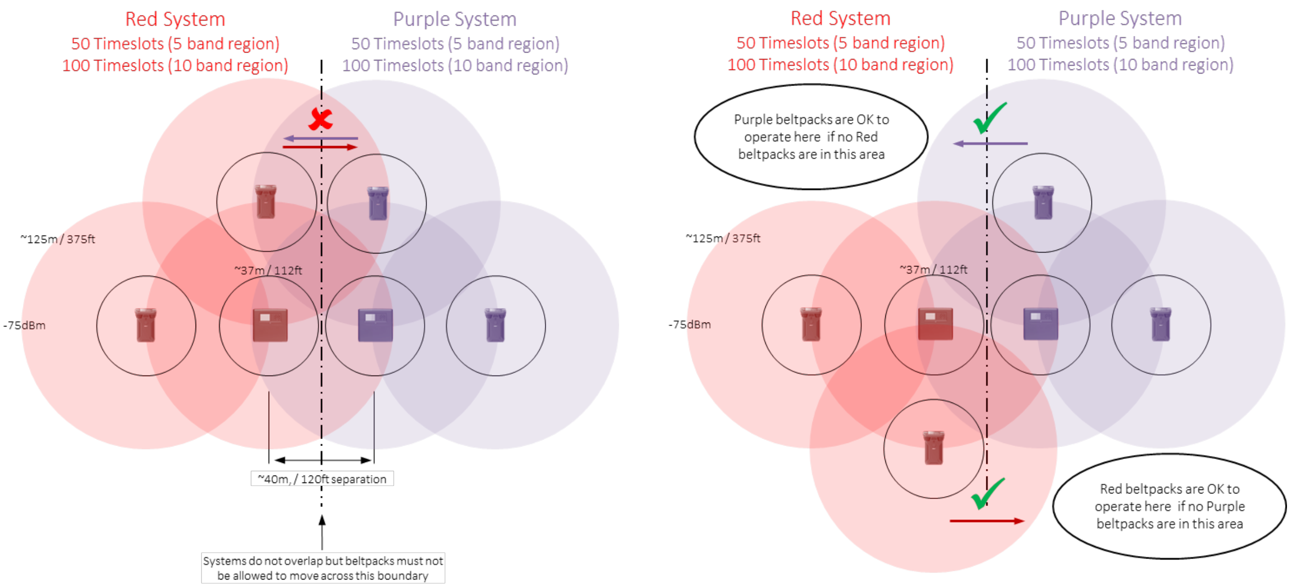
Figure 12: Antenna Separation Relative to Beltpacks at Edge of Range



This overlap means that both systems now use the same total count of timeslots which is ok as long as the maximum timeslot limits are adhered to.

It is possible to place antennas closer together but care then needs to be taken to limit where users with beltpacks from System 1 (Red) and users with beltpacks from System 2 (Purple) are allowed to move if both systems add up to more than the maximum timeslot limit of the region. This is shown in Figure 13 below:

Figure 13: Closely Spaced Antennas with Limits placed on Where Users Can Move in a Facility



In this example, two large independent systems are still possible with closely spaced antennas as long as the beltpacks are not allowed to physically move across the central boundary. If the total quantity of beltpacks for both systems is less than the total no of available timeslots for the region where they overlap then beltpacks from both systems can coexist across the above boundary.

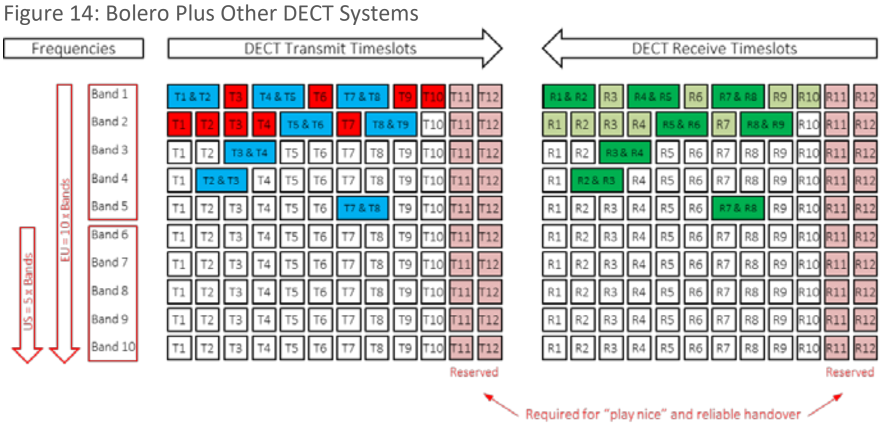
Interference

Interference can be caused by a variety of sources including multipath interference (caused by reflections from various building elements) that result in data with different temporal characteristics arriving at beltpacks at different times. Bit errors can be caused by power level issues, signal to noise ratio etc) and other devices consuming RF capacity.
Bolero has a multi-layered approach to reducing interference and mitigate multipath effects based on its unique ADR (Advanced DECT Receiver) technology.
Competing third party devices can appear as interference (i.e. a timeslot is already used therefore it cannot be hopped to). This is explained in the following section.
Note that often interference can be mitigated by relocating antennas in the affected area by only a few meters to reduce or eliminate the impact of the source.

Other DECT Systems in the Same RF Space

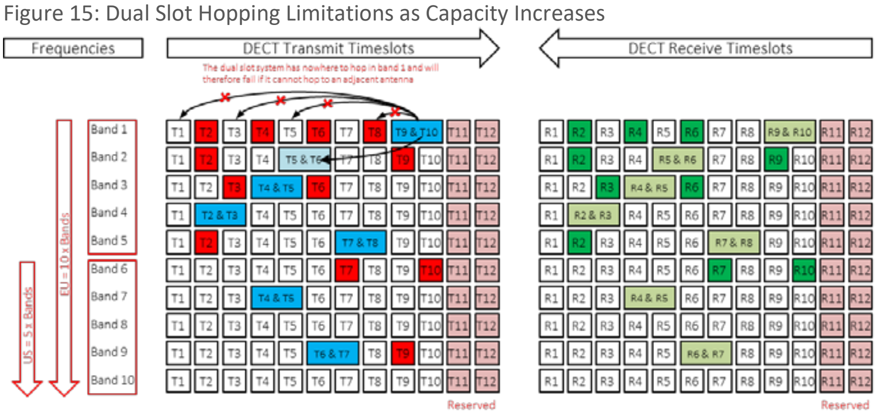
When other DECT systems are used in the same RF space there will be the potential for conflict depending on how the systems are deployed. In the worst case scenario, all systems would be used directly next to each other thereby consuming the maximum amount of RF space. In this case the 100 timeslot/50 timeslot rule would have to be applied. i.e. the total available RF capacity = number of timeslots minus the number of single slot beltpacks minus 2x the number of dual timeslot beltpacks.
So a 100 timeslot region could for example support 50x Bolero beltacks and 25x dual slot beltpacks in a 100% overlapping scenario and a 50 timeslot region could support 50x Bolero beltpacks or say 25x Bolero beltpacks and 12x dual slot beltpacks. This is shown in the following diagram:

Figure 14: Bolero Plus Other DECT Systems



You can see above how single slot and two slot devices can coexist. Each DECT system is randomly hopping across frequency bands and timeslots and handing devices over to different antennas if interference or antenna capacity is an issue. The single slot devices have the advantage that they only ever need to find one free slot whereas the dual slot devices need to find two free adjacent slots as shown in Figure 15 below:

Figure 15: Dual Slot Hopping Limitations as Capacity Increases



As more devices are used within the same overlapping RF space, dual slot systems have a bigger challenge to find available free slots compared to single slot systems. In the above Figure 12 at a certain point in time, Band 1 has four Bolero beltpack occupying T2, T4, T6 and T8. A dual slot device occupies slots T9 and T10. You can see that the dual slot device cannot use the available band 1 slots of T1, T3, T5 or T7 and must therefore hop into another band such as frequency band 2 and take T5 & T6 slots.
Single slot Bolero devices on the other hand, can freely hop into these spare slots thereby making use of the available slot capacity.

Synchronization and Other DECT Systems in the Same RF Space

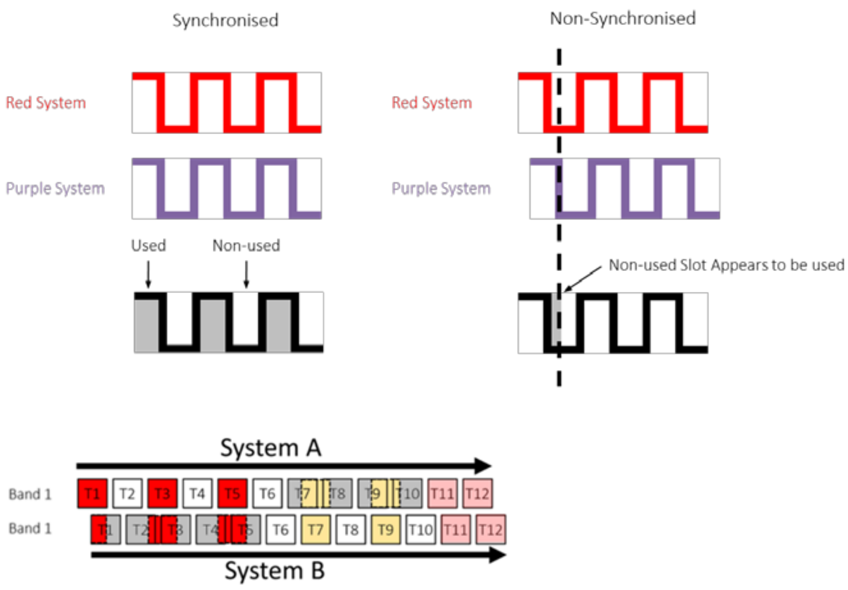
The final part of the RF capacity equation relates to the synchronization of single versus multiple systems. In order to seamlessly handover, each system needs it's DECT antennas to be synchronized to one another on a common network. This enables the system to precisely control the dynamic hopping of beltpacks across antennas, frequency bands and timeslots.

DECT systems from different manufacturers will have small differences in synchronization and timing. This is also true for multiple systems from the same manufacturer being used in the same environment for example multiple OB trucks from different broadcasters operating at the same venue independently.

If multiple systems are used in the same environment and they are synchronized to a common clock then their associated timeslots will be aligned. The phase aligned timeslots therefore appear as either full (100% occupied) or empty (0% occupied). This is the optimum use of available timeslots across the RF space.

If the systems are out of sync then the timeslots can overlap enough that non-used slots can appear used as shown below:

Figure 16: Synchronized Systems verus Non-Synchronised Systems



In the non-synchronised case the two systems now look like interference to one another. Each system is constantly scanning the environment looking for non-used and "clean" slots. Misalignment caused by a lack of sync means they will avoid "hopping" into these timeslots thereby reducing the overall capacity of the RF environment. This results in "wasted" timeslots that would otherwise lead to a higher or optimal capacity potential.
If the systems are isolated enough from one another due to the power separation described earlier then the synchronisation becomes a non-issue as the systems are able to re-use slots regardless of synchronisation state.

Summary

Predicting absolute capacity in a DECT based environment can be complex, being affected by many elements as described above.

In most cases, where the number of beltpacks and antennas never exceed the total timeslot capacity, the potential for issues is relatively small.

As the need for higher capacity increases, so does the need to optimise the number, placement and power separation of antennas in order to minimise interference and maximise capacity. In this case care should be taken to space antennas apart wherever possible and minimise the number of collocated antennas in the same 100% overlapping space (based on maximum capacity/density required in a given area).
A figure of 20dB power separation rather than 15dB can be used if an additional guard band is needed as a safety margin.

In an ideal world, all DECT systems would use a single timeslot DECT architecture in order to avoid the capacity and reliability issues associated with traditional dual timeslot systems.

Additional optimization can be achieved by synchronizing multiple disparate systems to the same time source, for example, PTPv2 (Precision Timing Protocol), in the case of Bolero Artist Integrated systems.

Bolero has demonstrated reliable operation in several largescale deployments (80 to 100 beltpack systems) in daily operation around the globe.

Like any RF environment, good planning and management enable the optimization of the system to provide the most ideal combination of range, capacity and performance.

Appendix

The following is a general summary of current intercom vendor system capacities. Note that this table is for general guidance only and individual manufacturers should be approached for their latest information.

Figure 16: Summary of DECT Intercom System Capacities (please refer to manfacturers for latest capacity information)

Manufacturer	Product	Slot Type	Codec	Handover Mechanism	Audio Bandwidth	Max No of Antennas per System	Beltpacks per antenna	Max No of Beltpacks per System	Antenna Network
Riedel	Bolero Artist Integrated	Single		Seamless Handover and roaming	7KHz	100	10	100 per NET Multiple NETS possible	SMPTE 2110-30 (AES67)
Riedel	Bolero Standalone	Single		Seamless Handover and roaming	7KHz	100	10	100 per NET Multiple NETS possible	SMPTE 2110-30 (AES67)
ClearCom	Freespeak 2 Eclipse Integrated IP Transceiver	Single		Seamless Handover and roaming	7KHz	64	10	64	AES67
ClearCom	Freespeak 2 Eclipse Integrated	Dual	G722	Seamless Handover and roaming	7KHz	40	4 with handover 5 without handover	50	E1
ClearCom	Freespeak 2 Basestation (standalone)	Dual	G722	Seamless Handover	7KHz	10	4 with handover 5 without handover	25	E1
RTS	Roameo Adam Integrated	Single	G726	Seamless Handover	3.5KHz	10	10	40	Omnio (Dante)
RTS	Roameo Adam Integrated	Dual	G722	Seamless Handover	7KHz	10	4 with handover 5 without handover	40	Omnio (Dante)
GreenGo	WBPX	Dual	G722	Roaming only	7KHz	4	4	16	Ethernet

