SCTE·ISBE CABLE-TEC EXPO 2018 | ATLANTA, GA OCTOBER 22-25

2018 Fall Technical Forum SCTE·ISBE • NCTA • CABLELABS

Evolving The "Box": The Smart Set-Top Box

A Technical Paper prepared for SCTE•ISBE by

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Introduction

The set-top box (STB) has long been the cornerstone of video decoding TV services for the service provider. However, now it is being recognized and marketed as a device that does a great deal more. This paper explores the value of the device that is in multiple rooms, is the gateway to the pixels on the screens, and offers the scope to be leveraged as an Internet of Things (IoT) Hub and a smart assistant – 4 for 1 (or more) functionality in a single box.

This paper offers readers options and challenges for leveraging the STB for video, IoT, natural language-based voice services and more. The paper discusses the technologies of voice detection in a noisy environment, out of phase surround sound, and the challenge of making the smart STB support IoT, microphone, and speaker technology from lower end devices all the way up to high end offerings with high quality speaker solutions. How will service providers maintain control of the pixels and continue to provide value to their subscribers?

The Primary Job & Evolving the "Box"

The STB has had he primary job of helping the subscriber navigate and play back video content that is offered by the service provider.

Figure 1 – Video Playback (the Primary Job)

The STB fills the following traditional roles:

- Acts as a consistent / known end point for the provider's video delivery network
- Provides a UX for accessing video services
- Connects to the Television (TV) / home theater

The STB performs that job securely and reliably to assure a level of service expected by the service provider and to ensure all content provider / content protection requirements are met.

Over the years certainly features & connectivity have changed:

- Analog to Digital tuners and CableCARD to Internet Protocol (IP) delivery
- Standard-definition to High Definition (HD) and now Ultra High Definition (UHD) / 4K
- Single tuner HD boxes to multi-tuner Digital Video Recorders (DVRs) to IP clients & cloud DVR
- Linear broadcast to On-demand to IP video apps such as Netflix and YouTube
- Analog audio/video outputs to High-Definition Multimedia Interface (HDMI)

However, the primary job of the STB has remained mostly the same.

Meanwhile many new consumer devices & new experiences have emerged, and the home is filling up with many single-purpose devices with varying capabilities & non-integrated user experiences:

- Smart assistant devices
- Wi-Fi access points & extenders
- Soundbars and small Bluetooth speakers
- 4K and HDR capable TV displays
- IoT hubs and devices, cameras and connected 'smart' sensors

How does the STB continue to provide value to the subscriber and to the service provider with this multitude of gadgets and technology?

The STB is a unique device – it is in multiple rooms and where consumers spend a lot of time.

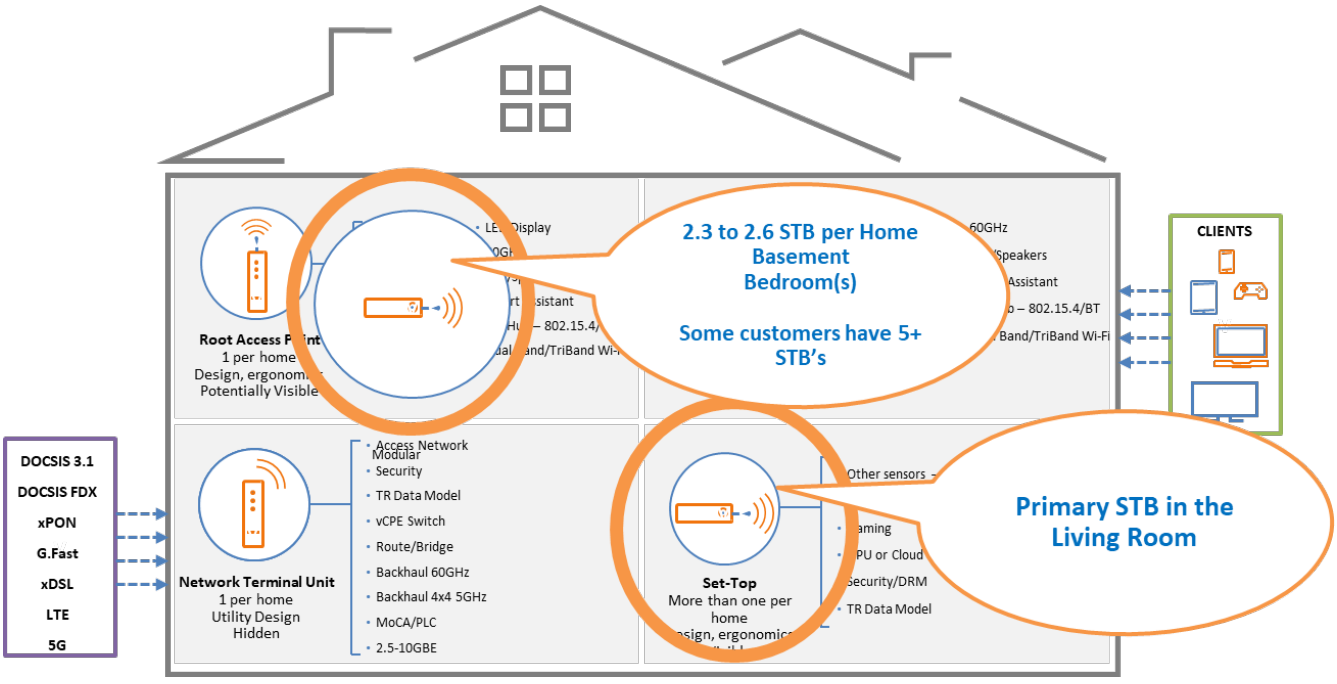

Figure 2 – Where STBs are Located

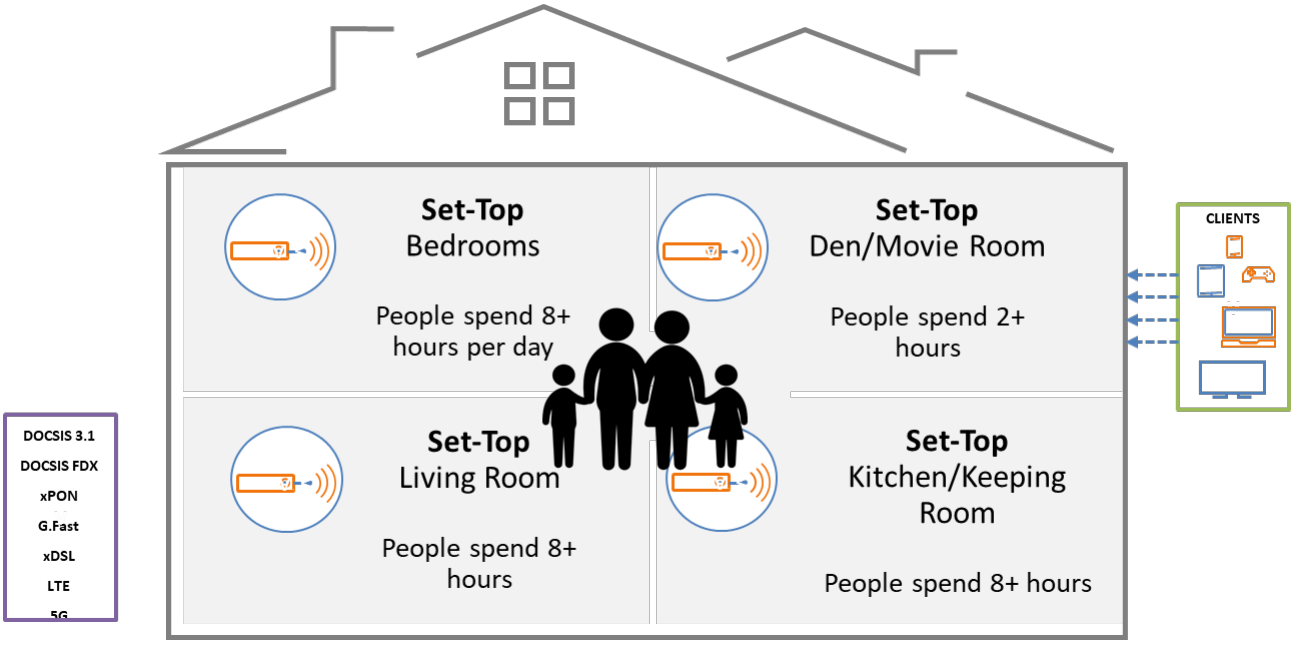

Figure 3 – Time Spent in Locations

It is hard to get a consumer device located in multiple rooms – the consumer must value its purpose in each room separately.

Given that advantage of the STB, what more can we do with the STB device and its functions?

- People prefer less devices ----- Avoid device clutter
- People prefer simple than complex ---- Ease of use
- People like using the large screen for communal and family things. Small screens are used for private activities
- The "Large Screen" in the home is evolving to more of a home control panel with visual and audio outputs
- Consumers care about Household monitoring functions like Carbon Dioxide (CO) or Radon – but maybe haven't considered this safety feature integrated into another device
- Consumers show a growing interest in audio throughout the home in multiple rooms for multi-room listening

Figure 4 – Evolve the Box

We must ask: **How should the STB evolve?**

Think of the "box" as a connected node…a **smart STB**:

- Network connected
- Located in multiple rooms & where consumers spend time
- Connected to the "Large Screen" and audio output
- Capable of additional interfaces & sensors
- Interactive

By leveraging this ability, you can evolve the traditional STB to a smart STB!

Anatomy of the Smart STB

The anatomy of the smart STB includes all the core elements that are evolving and can be integrated in new products. We will explore each of these in further sections.

- Audio/Video Processing
- Central Processing Unit (CPU) / Graphics Processing Unit (GPU)
- Wi-Fi
- Bluetooth / Zigbee
- Microphone / Speaker
- Sensors
- Long-term Evolution (LTE) / 5G
- Form factor & placement

Audio / Video Processing

Compelling A/V experiences & more codec options for the provider to leverage:

- 4Kp60 – p120 High Frame Rate
- High Dynamic Range (HDR)
- High-efficiency Video Coding (HEVC), AV1
- More immersive audio
- 8K

The cornerstone of the device is providing the highest quality video rendering to the display and audio output. The value and likely usage of the device is significantly reduced if the consumer gets 'trained' to want the perceived better video quality directly from their Smart TV apps or other connected device.

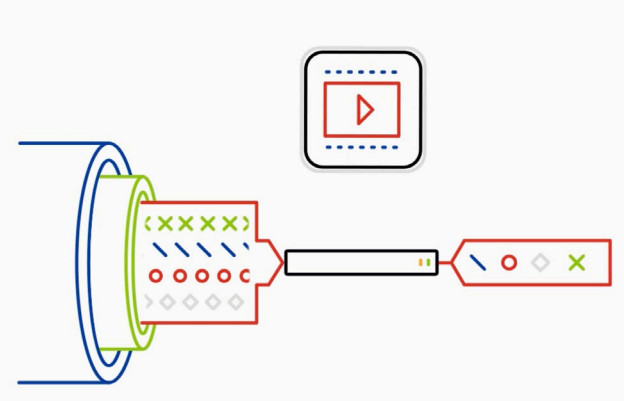

Figure 5 – Audio/Video Processing

Newer and emerging video technologies can benefit both the subscriber via improving video quality but can also benefit the service provider via more efficient use of bandwidth and adapting to needs of various content providers. New video and audio codecs may be required for new services or can help reduce cost of licensing and implementation.

Challenges:

- Most of these advancements require newer / emerging silicon
- TV / Home theater interoperability issues will arise
- Consumer confusion over nomenclature and support
    - Example: Many consumers know they have a "4K" TV they purchased over the past several years. Newer TVs will claim support for HDR and/or wide color gamut, etc. but TVs can range from 400 to 2,000+ nits of brightness and varying video processing capability.
- Content availability / delivery

The end-to-end delivery including content production, delivery, smart STB, HDMI cable and TV, and even any HDMI repeater or an Audio/Video Receiver (A/VR) home theater system, must all work together to ensure the best experience. A smart STB must provide premier A/V capabilities, adapt to the consumer's connected TV and audio system, and provide meaningful information to the service provider and consumer to identify any interoperability issues.

CPU / GPU

Figure 6 – CPU/GPU

The CPU and GPU of the smart STB help keep the consumer engaged with:

- User Experience (UX) - fundamental
- Content Navigation with high-quality artwork - fundamental
- 360 / Immersive video – new and untapped
- Gaming - untapped
- Virtual Reality (VR) / Augmented Reality (AR) – new and potential parallel experiences

Silicon in the STB space is evolving to lower power (watts) but dual and quad core CPUs providing 15-20K+ Dhrystone MIPS (DMIPS) of processing power for applications. 2D/3D GPUs and overall system memory bandwidth and improved video display pipelines can support higher-end graphics to keep up with the 4K HDR video experience.

Some of the challenges:

- Potentially higher cost as the very latest silicon is made available
- Need to identify value-add experiences and focus on those
- Accessory/headset compatibility
- Leveraging the remote control (or even voice) to navigate
- Ecosystem (content, apps, partnerships)

It is natural to consider dedicated gaming consoles and high-end gaming PCs as competitors in this area. However, the smart STB has the advantage of being in multiple rooms, in a small and quiet form factor

and well-integrated with the service provider experience for video content. The smart STB could be a client to streaming gaming services or in-home streaming from consoles and high-end PCs.

Wi-Fi

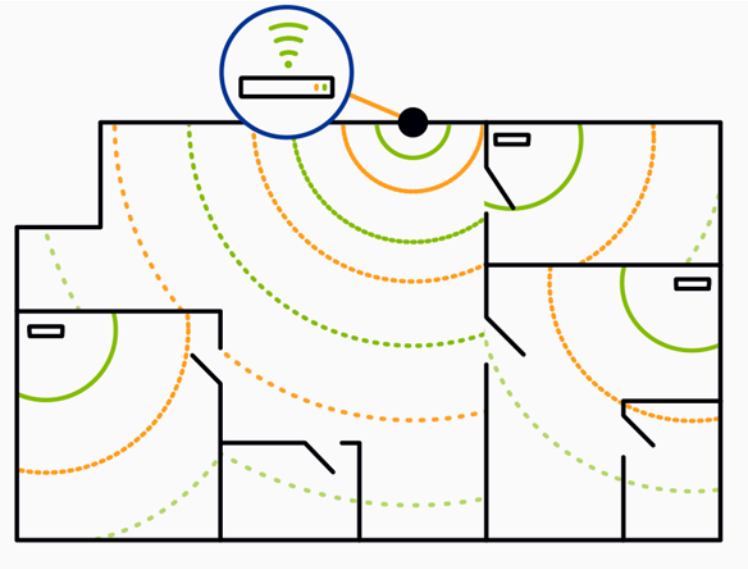

Figure 7 – Wi-Fi

Wi-Fi in the smart STB can be used for video delivery from a gateway, but can also be designed as Wi-Fi Extender (STB can be wired, or wireless backhaul)

- Flexible installation – not tied to coax outlet locations
- Located in a room likely to have other Wi-Fi clients
- Sense other Wi-Fi devices in the room
- Provide health of the Wi-Fi in that part of the home
- Emerging 802.11ax for latest Wi-Fi
- 802.11ad 60 GHz for highest same room performance

Challenges:

- Extender adds cost & power and impacts size of the STB
- Backhaul connectivity & performance

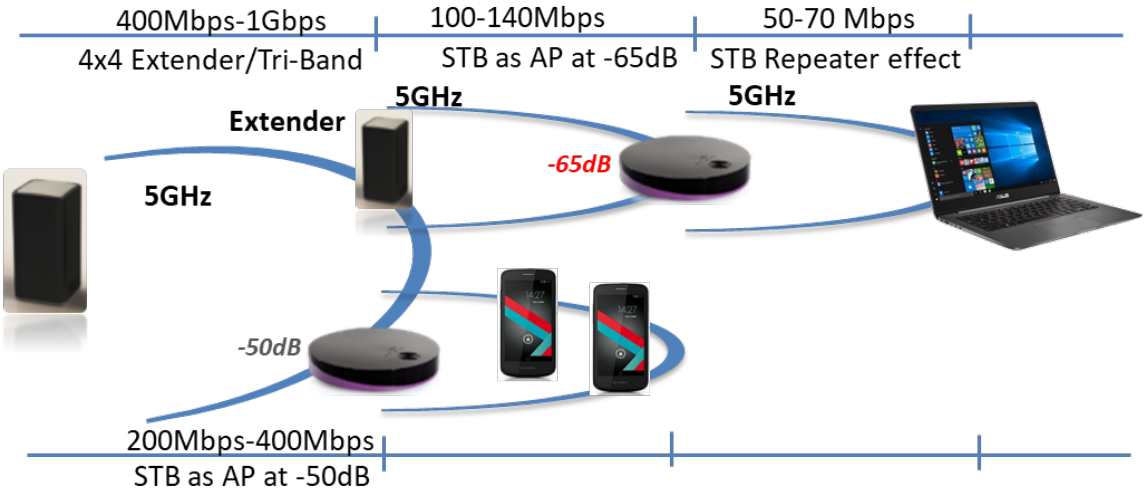

Figure 8 – Bandwidth and RSSI

It is not recommended to go beyond -65 dB RSSI (Received Signal Strength Indicator) when deploying a Wi-Fi STB to ensure sufficient performance for video stream delivery.

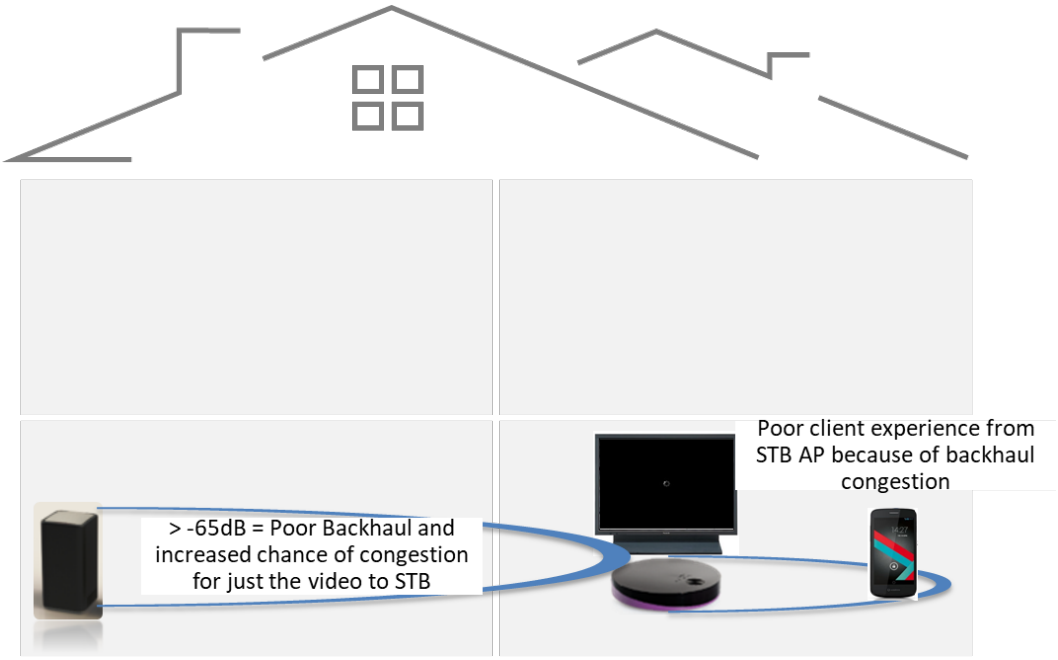

Figure 9 – STB Location and RSSI

STBs go where the RSSI may be > -65 dB typically which can still allow for video delivery but may result in backhaul congestion for extender use case.

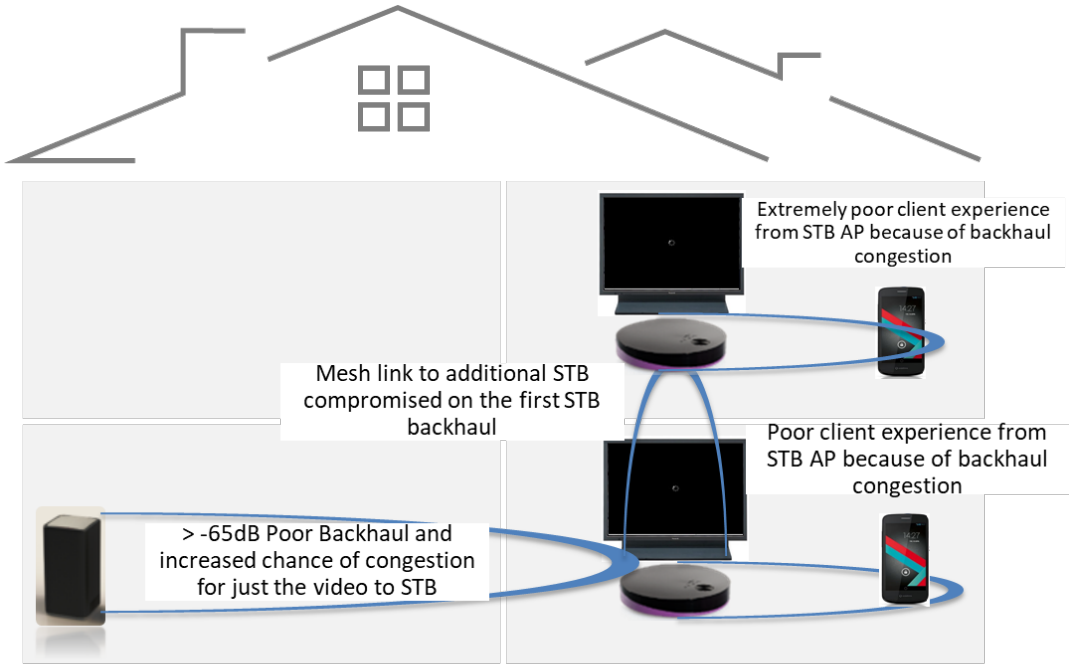

Figure 10 – STB / Extender Location and RSSI

Poor Wi-Fi client performance / experience is likely if a mesh link between 2 STBs acting as extenders is used due to backhaul congestion. Even the prioritization for the video streaming may suffer and be inadequate.

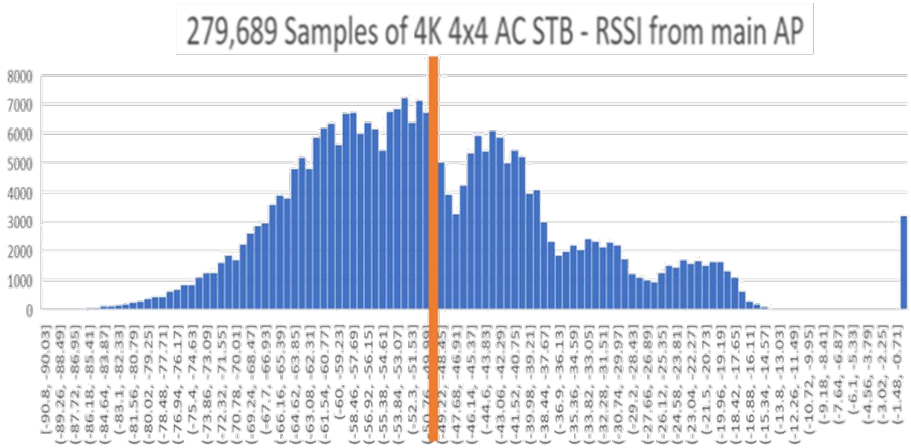

Figure 11 – STB Location / RSSI

Due to TV placement, the STBs end up in remote locations in the home driving RSSI concerns.

Figure 11 shows a large dataset of ~280K 4K 4x4 Wi-Fi STBs.

- Majority > 50 dB path loss from primary AP
- At -65 dB it is recommended to add a Wi-Fi extender even to support primary 4K video feed @ 25 Mbps

The STB can be a secondary extension device once primary extender strategy has been deployed.

Another consideration/challenge is that the STB can also be turned off. STBs need to sleep to drive energy saving metrics (~1W).

The form factors of the STB can also influence using the device as a Wi-Fi Access Point (AP). For example, a larger soundbar enclosure can allow for additional space for antenna diversity, but placement within the enclosure can also face challenges in certain directions due to the speakers and other components that may be in the way.

A small form factor encourages poor placement for Wi-Fi such as behind a TV, or on the wall.

A very small dongle device may only allow 2x2 solutions with very minimal antenna diversity and also encourages poor placement for Wi-Fi.

Table 1 – Wi-Fi Configurations

Single-band 5G	Lowest $	Smallest size	Focus on video
DBS 2.4 / 5G	Mid $	Mid size	Avoid 2.4 for video
DBC 2.4 / 5G	Highest $	Largest size	Avoid 2.4 for video

There are several considerations for selecting a Wi-Fi radio and antenna configuration for a video + extender scenario.

A wired back-haul may be considered, but interoperability on both ends is required and may not be feasible (e.g., MoCA in the gateway + set-top). A Tri-radio (dedicated 5 GHz) backhaul that is found in various solutions in the marketplace may be considered but adds cost and size to the STB.

- A single band 5 GHz radio can suffice if a separate 2.4 GHz Extender architecture exists; this can still provide value to push 5 GHz reliably throughout the home
- Dual-band switched (DBS) is not ideal as video should not be on 2.4 GHz
- Dual-band concurrent (DBC)
    - Use 5 GHz + QoS for video delivery
    - For wireless repeating a 2x2 or 4x4 halves the bandwidth (4x4 preferred)
    - Using 2.4 GHz as the backhaul protects the 5 GHz video delivery but may not meet performance expectations

IoT - Bluetooth / Zigbee / RF4CE

Figure 12 – IoT

Numerous experiences can be supported with the (re)use of existing STB radios being used for remote control support. In particular a Bluetooth LE remote can be used for IoT device connectivity as well. Addition of low power ZigBee / Z-Wave radios are also feasible.

- Wireless remote (no line of sight)
- IoT hub, Security & Presence detect
- Audio streaming (in/out)
- Push to talk voice control of Smart Assistant - near field mic in remote

Wireless remotes are already deployed in millions of STBs – far superior to IR traditional remotes and support additional data/connectivity (such as voice in remote) capabilities already deploying with service providers.

For IoT Hub / Security the smart STB can connect to devices to extend coverage as part of the mesh network and can display status on TV and provide other interactions and controls (such as controlling lighting or turning off cameras).

Presence is a capability long mentioned in the STB space but not well-integrated today. The standard is the profile selection via remote control used with OTT services today. Why not take advantage of the smart STB Bluetooth or Wi-Fi connection that can detect personal device, namely smartphones that are rarely far away from the individual consumer?

Audio streaming, when described to consumers, is an under-appreciated feature. Imagine using your wireless Bluetooth headphones or Bluetooth connected audio speaker system with your smart STB.

- Privacy – listen to your favorite program at night without disturbing your family, or be able to listen to the news while your family chaos spins around you
- Accessibility – have a dialog enhancement version or descriptive video service track sent privately to your headset while rest of the family can listen on the TV
- Second language – send a different language track to the headset vs. the TV
- Voice chat – gaming headset style or for standard Voice over IP (VOIP) phone conversation via your smart STB

Challenges:

- Interoperability / Pairing & Connection, (Ease of use)
    - Any connection (Bluetooth or Zigbee, etc.) to a device needs to be automated where possible or UX assistance may be needed to guide the consumer
- 2.4 GHz coexistence between Bluetooth, Wi-Fi and other 2.4 GHz radios must be considered
- RF4CE only STBs may not be dual-stack and therefore may only support remote control use cases and may not be capable of also communicating to Zigbee devices

Microphone / Speaker

Far-field voice and optional speaker or soundbar integration provide new interactivity

- No remote needed
- Smart assistant
- Voice calling
- TV audio / soundbar

Adding a microphone to the STB has challenges due to determining the best location and number of microphones. Placement behind a TV, in an enclosed shelf or oriented vertically on-wall may lead to insufficient performance for voice input. However, they are small and may not materially affect size of STB.

Adding a speaker to the STB can substantially affect the size and the power consumption of the device. The speaker(s) can be sized and designed just for basic tone and voice feedback or provide full-range output for music in varying performance levels. Specific design experience for acoustic tuning is crucial.

Speakers in the STB can be omitted in favor of using the built-in TV speakers or home theater, but voice assistant use cases that require feedback would need the TV / audio device to be on. Using HDMI Consumer Electronics Control (CEC) or other capability to turn the TV on to provide feedback is likely not a desirable experience / not expected by the consumer.

2-4 watts of speaker amplification for mass market smaller devices may suffice. A premium audio experience can be delivered in a soundbar form factor that is integrated with the STB. A soundbar with 20 watts+ of amplification provides both an improved audio experience and a more consistent install performance for far-field voice & speakers (vs. small STB placed behind TV). The consumer is much more likely to perceive higher value from the soundbar.

Another benefit to including far-field voice is that consumers no longer need to worry about a lost remote or changing the remote's batteries.

Adding microphones, voice Digital Signal Processing (DSP) chips (if not integrated into the STB chip), optionally speakers along with all the mechanical considerations for mounting and isolating the components certainly adds cost to the STB.

Of course, audio privacy is critical in this growing area of consumer adoption. The need for a physical mute button with very clear indication of when the microphones are disabled is well understood.

One of the challenges in far-field voice that we will dive deeper into within this paper is how to detect the barge-in / key word to trigger the voice assistant functions.

When the TV is playing, and this sound is generated by the STB decoder output – then the DSP in the STB voice processing unit – can invert the sound in – to be able to effectively cancel it from the sounds in the room detected by the microphones.

When the TV uses a surround sound system – it's slightly out of phase to the original source and amplified – it is so much harder to cancel.

Similarly, for the Smart Assistant if the sound on the TV comes from an additional HDMI input source it is harder to cancel.

To support voice control & barge/keyword detection in a home environment, several techniques can be considered and balanced against cost such as DSP, mics, and memory along with needed performance for the solution.

- Beamforming
  - Broadside
  - Endfire
- Blind Source Separation (BSS)
  - Independent Component Analysis (ICA)
  - Degenerate Umixing Estimation Technique (DUET)

1. Broadside Approach

An array of microphones is oriented perpendicular to the general direction of the command sound sources. It isolates sound sources in a room by removing sounds coming from angles relative to the orientation of the microphone array. This is done by time shifting the microphone signals and adding them together.

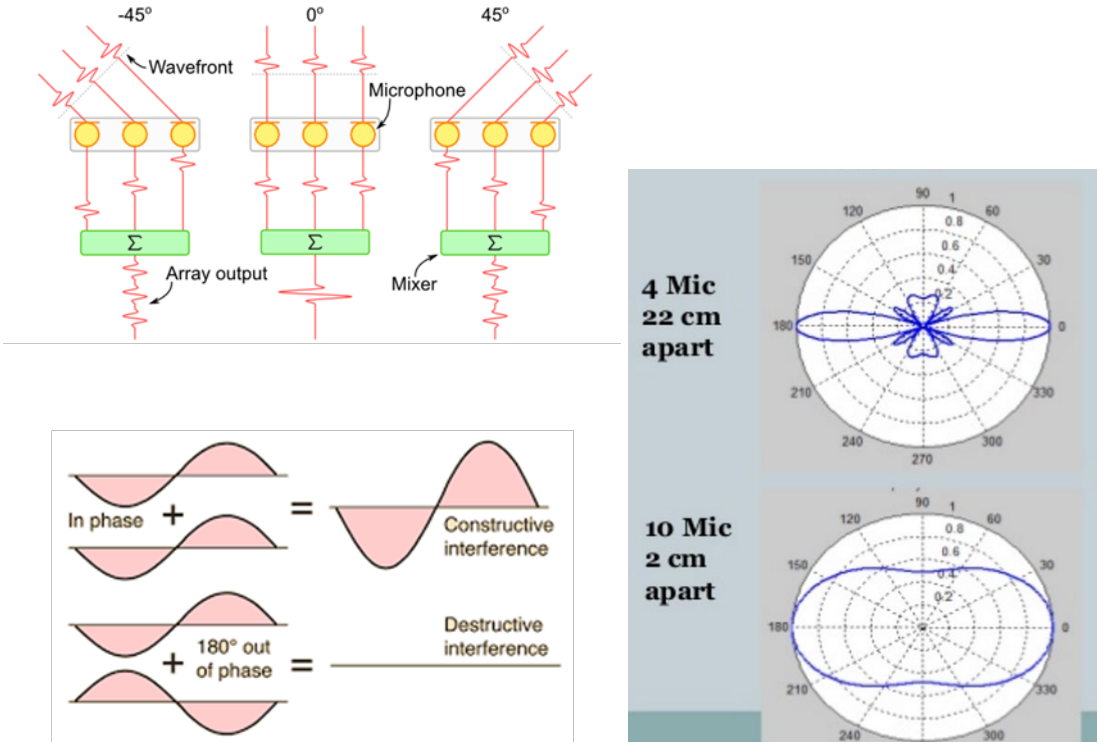

Figure 13 – Broadside Approach

Advantages

- The direction from which sounds are picked up is 'steerable' to maximize receptivity from that location, while minimizing sounds from other directions
- The DSP is straight forward and requires little memory

Disadvantages

- Picks up sounds equally well at 180o from the 'steered' direction at the same time (Example: If a TV is behind the microphone array, it will pick up the TV audio along with the command voice in front)
- 2 mics needed to ease the spatial selectivity, (narrow window angle over which sounds can be picked up)

2. Endfire Approach

An array of microphones is oriented in the general direction of the command sound sources. Sounds from behind are removed while sounds from in front are detected. This is done by time shifting the microphone signals and subtracting them. The further you place the microphones the narrower the sound receiving angle becomes, at the expense of less sound removal from behind.

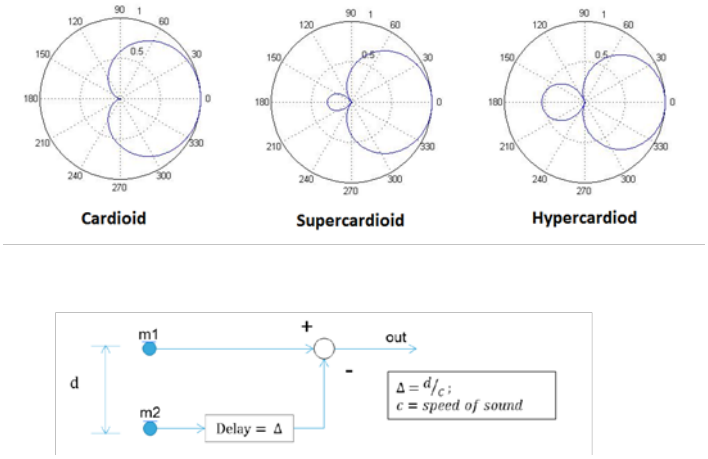

Figure 14 – Endfire Approach

Advantages

- Can completely remove sound noise from almost the half of a room (e.g., remove interfering TV sounds if product is in front of the TV speakers)
- DSP is straight forward and requires little memory

Disadvantages

- Picks up sound at an angle in the vicinity of +/-90o, depending on the spacing of the microphones
- Adding microphones will not improve the spatial selectivity much

3. Independent Component Analysis (ICA) Approach

The vocal source signal amplitude varies with a Super-Gaussian distribution.

A source signal at a moment in time can be thought of as a sample in an N-dimensional grid space, where each orthogonal dimension axis is a microphone reading. A source signal sample is described by an N-element coordinate value in this space.

If the basis vectors are rotated so that one lines up along a direction of Super-Gaussian distribution, and we assume that all other sound sources are independent (orthogonal) to this direction, then only data on this axis with Super-Gaussian distribution is assumed to belong to a single voice.

The voice signal can be isolated by only taking the sample values along this axis.

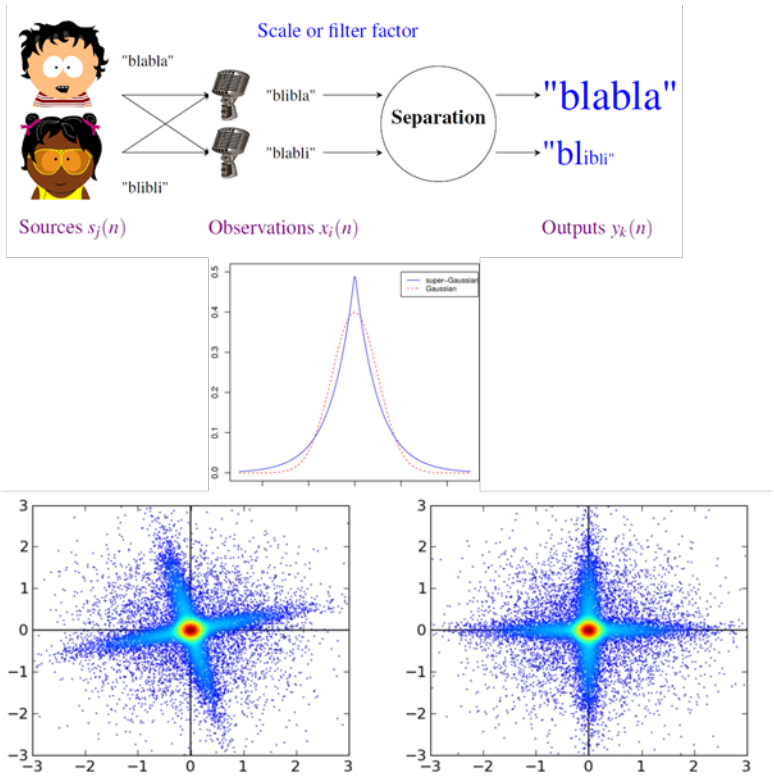

Figure 15 – ICA Approach

Advantages

- As few as 2 microphones can be used to separate two sound sources (Example: One command voice and a TV)
- The source sounds that are separated can be placed anywhere in the room as long as they do not come from the same direction of arrival
- The mic arrangement and distance is flexible, as long as their relative positions are known. This allows one to place mics away from known noise source locations, to improve the signal to noise ratio (SNR) of extracted command signals.

Disadvantages

- The number of sound sources in the room, must not exceed the number of mics used, in order to cleanly separate the sounds
  (Example: many mics required to isolate a command voice during a party)
- DSP is very involved and requires much memory

4. DUET Approach

A sound sources direction of arrival (DOA) is uniquely related to the delay time (phase difference) from when it reaches one microphone to the next.

Excited frequencies belonging to a single sound source will fall along a constant phase angle. Therefore, we can reconstruct a single sound source audio from just those spectral components associated with a particular source phase angle.

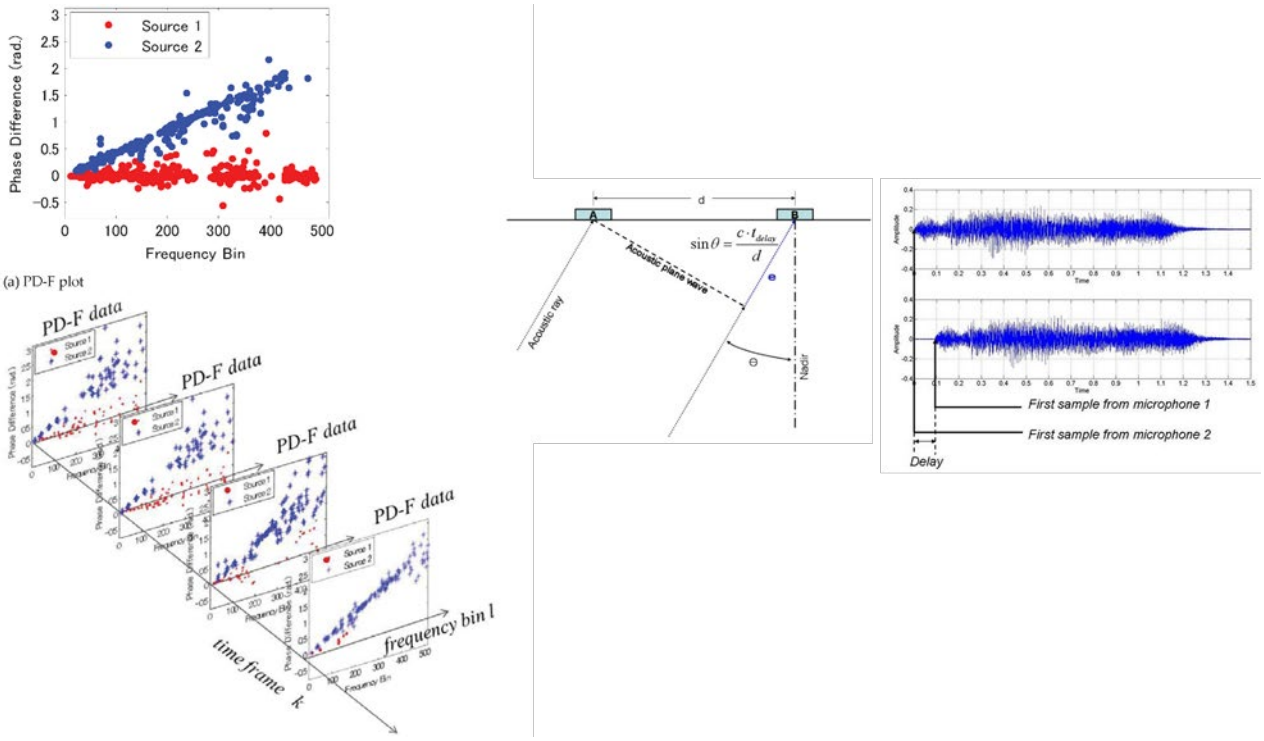

Figure 16 – DUET approach

Advantages

- As few as 2 mics are necessary to separate any number of sound sources - although the quality of sound source separation diminishes with an increase in # of sources
- The source sounds that are separated can be placed anywhere in the room as long as they do not come from the same direction of arrival

Disadvantages

- Traditional use of DUET requires that the mics be placed no more than ~2cm apart, because the source location is determined in the frequency domain (as opposed to the time domain, such as ICA)
- Undesirable artifacts can be created and may be difficult to remove because of the conversions to/from the time/frequency domains
- DSP is very involved and requires much RAM

Sensors

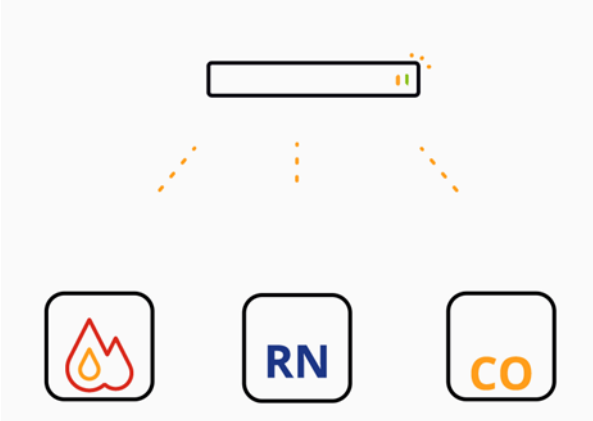

Figure 17 – Sensors in a Smart STB

A connected node smart STB is part of the home network and can help with the "health of the home". A few sensors to consider include:

- Smoke / heat detector
- Radon monitor
- CO / carbon monoxide detector
- Security / glass break & presence

It is worth exploring new revenue opportunities from these sensors. Some states in the US now mandate a 90 day radon report before selling a house. Consumers may also value continuous monitoring and notifications/reports. Could this be a $1 per month service from STB location?

A smart STB with far-field voice could possibly leverage the mic and DSP for security monitoring such as glass break, door opening, gun shot, or presence detection. False alerts could be managed by checking for known / trusted devices (Bluetooth or Wi-Fi to smartphones).

When integrating these sensors, the design must consider placement and size. A small plug-mount smart STB could contain a CO detector, but a ceiling mount smart STB may be more appropriate for smoke detection and could be combined with Wi-Fi Extender and 60 GHz wireless HDMI to the TV. There is opportunity to explore the right form factors and designs.

Challenges include any unique installation factors or setup and for certain sensors the needed safety & compliance evaluation & design must be considered. Sensor lifetimes should be evaluated to match with expected STB deployment lifecycle (e.g., if a CO sensor is rated at max 5 years) and consumers need a means to be notified of sensor status and if any replacement capability exists.

LTE / 5G

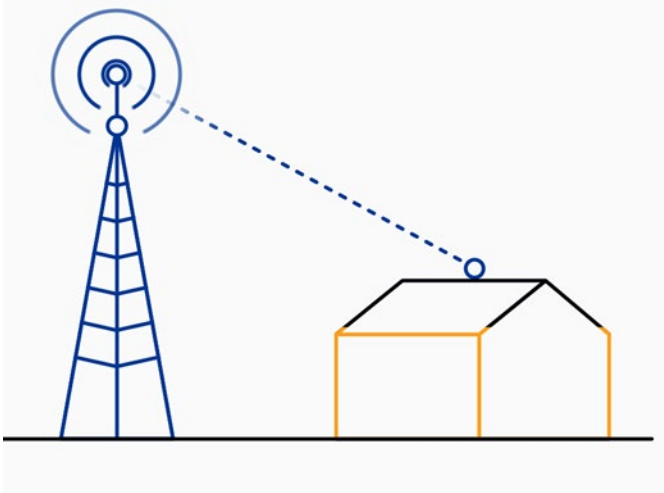

Figure 18 – LTE / 5G in a Smart STB

The smart STB can connect to the service provider network over 4G LTE and emerging 5G WAN network.

Fixed Wireless Access (FWA) allows for rapid deployment and no waiting for cable wiring to the home.

The download bandwidth should be able to sustain at least 5 Mbps for video and up to ~18 Mbps for 4K video when using FWA.

LTE modules are now available in small M.2 form factors to minimize the additional space required inside the STB. Antennas can be installed inside the plastic enclosure to avoid external antennas visible to the subscriber. CAT-4 and CAT-6 and even higher performance modules are available that exceed 150 Mbps capabilities with use of 2 or more carrier aggregation support in LTE-A.

Challenges:

- 5G networks still in early phases
- Placement in the home needs evaluation – will there be sufficient signal deep into a home
- Subscriber Identity Management (SIM):
    - A SIM slot can be included, although this requires either the subscriber installing one or the service provider pre-installing one and possibly having to deal with replacements if needed
    - An eSIM can be used, but the service provider and network need to support this technology & associated provisioning

Form Factor and Placement

The smart STB can take on many forms and be placed in different way. You may wish to make a bold statement ‘out front’ or blend / hide the device and focus on the TV UX. Features such as voice or Wi-Fi or sensor performance capabilities / cost may dictate the form and placement as well.

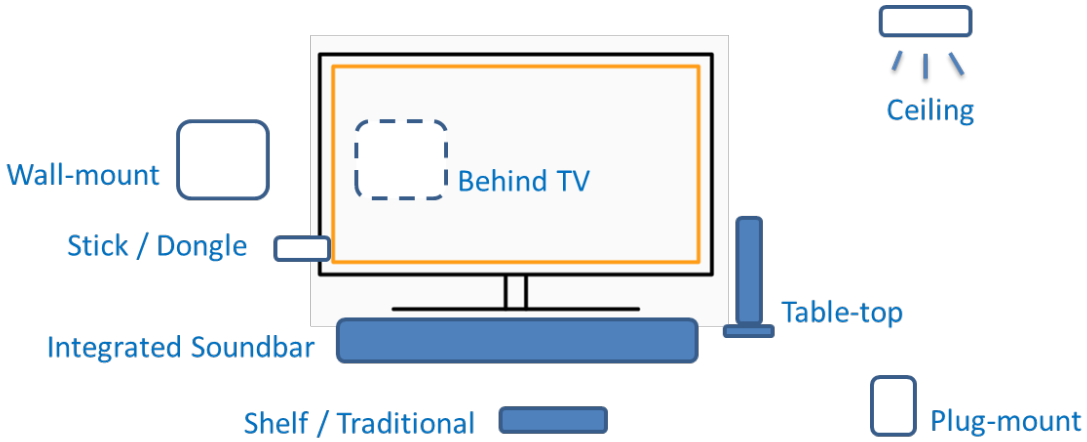

Figure 19 – Form Factor and Placement Examples

A portfolio of devices can be explored to adapt to different market and consumer needs. A lower / mid-range target for mass market may have select smart STB features and lower power audio if speakers are integrated.

Higher-end devices can push the performance barrier with latest CPU/GPU capabilities for VR and immersive experiences or can be a soundbar smart STB that complements the latest 4K HDR displays.

Figure 20 – Smart STB solutions

Consumers value the benefit in ergonomics – one device vs. 4 or 5 in a high traffic room. The smart STB that combines multiple functions can provide this value.

Services

The smart STB can provide new services on the Large Screen in the home.

- Room console – control your lighting and room environment and Wi-Fi
- Home security controls and camera viewing / notifications
- Education
- Visual UX smart assistant feedback
- Shopping
- Home / energy management
- Aging in place / health management
- Child management

Figure 21 – Smart STB services

Aging in Place:

- Health stats & notifications (time for medication) – pause TV for compliance
- Connect to sensors for blood pressure, weight, pulse

Energy Management:

- Show latest energy bill and usage on-screen
- Compare usage to last month / last year

Home Console for the room:

- Control lighting, security, sound, and connectivity (Wi-Fi health)
- Visual (UX) Smart Assistant feedback
- No need to rely just on voice feedback – the smart STB can present information and responses / actions on-screen

Education:

- Integrate online courses with an on-screen UX
- Family experience with children & reward with TV time after

Child management:

- Parental controls for TV and Wi-Fi / devices
- View reports and status

Benefits to the Service Provider

The smart STB provides differentiation and enables the ability to offer additional services & value. This could provide additional revenue opportunities and subscriber retention and higher perception & ratings of the service.

- Extend services deeper into the home (beyond the gateway/network demarcation)
- Multiple end-points throughout the home that can have new leverage and services
- Service provider 'owns' the largest screens in the home
- Controls the quality of connection of service
- Adds new combined Internet/Visual UX/IoT/Lifestyle Services to the TV
- Drives new opportunities like commerce on TV, Education on TV, Aging in Place on TV – all with connectivity control

Conclusion

The smart set-top box provides an integrated experience and contains multiple devices in single device:

- 4K HDR video playback
- Smart assistant / voice
- IoT hub & sensors
- Audio / soundbar

The Smart STB. The "Box" can Evolve.

Abbreviations

A/V	Audio/Video
A/VR	Audio/Video Receiver
AR	Augmented Reality
bps	bits per second
BSS	Blind source separation
CEC	Consumer Electronics Control
CO	Carbon Dioxide
CPU	Central Processing Unit
DBC	Dual-band concurrent
DBS	Dual-band switched (or selectable)
DMIPS	Dhrystone MIPS
DOCSIS	Data Over Cable Service Interface Specification
DSP	Digital Signal Processing
DUET	Degenerate Umixing Estimation Technique
DVR	Digital Video Recorder
FWA	Fixed Wireless Access
GPU	Graphics Processing Unit
HD	High-definition
HDMI	High-Definition Multimedia Interface
HDR	high dynamic range
HEVC	High-efficiency Video Coding
ICA	Independent Component Analysis
IoT	Internet of Things
IP	Internet Protocol
ISBE	International Society of Broadband Experts
LTE	Long-term Evolution
LTE-A	Aggregated Long-Term Evolution
MIPS	Machine Instructions Per Second
MoCA	Multimedia over Coax Alliance
RSSI	receive signal strength indicator
SCTE	Society of Cable Telecommunications Engineers
SIM	Subscriber Identity Management
SNR	Signal to noise ratio
STB	Set-top box
UHD	Ultra high-definition
UX	User experience
VOIP	Voice over IP
VR	Virtual Reality
xDSL	Variations of Digital Subscriber Line
xPON	Next generation Passive Optical Network

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