Forecasting Short-Term Cellular Traffic Evolution During a Spectrum Transition

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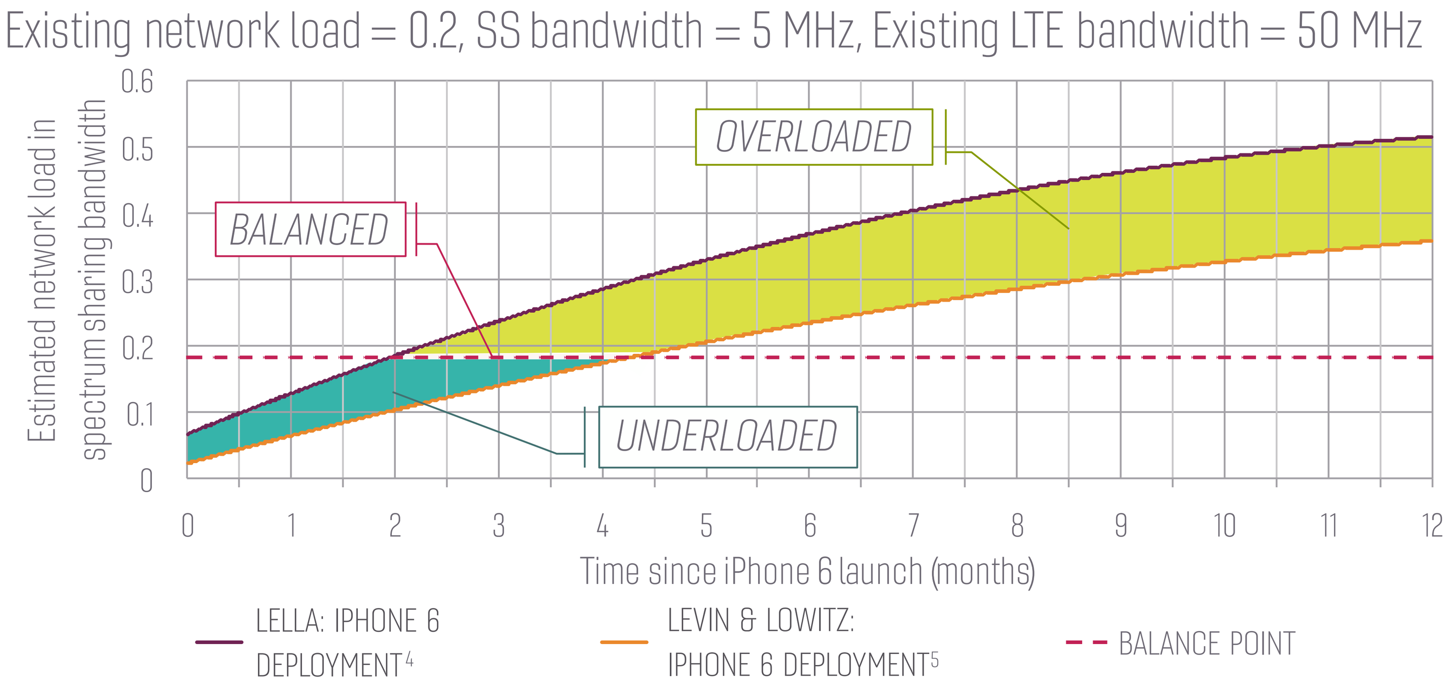
Introduction

- During a *Spectrum Transition* (ST), wireless spectrum resources are moved from one exclusive user to another user – e.g.,
  - The Advanced Wireless Services 3 (AWS-3) transition.
- Outgoing users provide critical services to society:
  - NOAA operates weather services in AWS-3[1] – e.g.,
    - Hurricane intensity and location analysis,
    - Sea surface temperatures, and
    - Search and rescue.
- Incoming users are eager to deploy and also provide beneficial services to society – e.g.,
  - Wireless carriers want to improve their LTE networks:
    - T-Mobile deployed AWS-3 spectrum in their network in 2016[2];
    - In March 2018, Verizon Wireless requested FCC permission for AWS-3 field trials[3].

CASE STUDY: HISTORICAL IPHONE 6 LAUNCH

Existing network load = 0.2, SS bandwidth = 5 MHz, Existing LTE bandwidth = 50 MHz



FORECAST REPRESENTS *SHORT-TERM* EVOLUTION AND AN *EQUILIBRIUM* NETWORK TRAFFIC *BOUNDARY* FOR SS

- With the addition of SS bandwidth, an LTE system can spread traffic across more network resources in the *time* and *frequency* domains.
  - In LTE, a time-frequency resource is called a *Resource Block* (RB).
- The evolution of traffic from an incoming LTE system can be modeled as scenarios describing *resource availability* based upon the number of deployed LTE devices that support the SS band, SS band deployment, and how an LTE system assigns resources in SS bands.
  - There are *many, many* different network parameters that affect network loading in a particular channel.
    - To illustrate, the figure above presumes the LTE scheduler's objective is to distribute resources *equally* across the network (see simplifying assumptions, on right).
    - Model parameters can be *adjusted* to *accommodate* different LTE deployment and operation strategies – and are ideally *tailored* to a given LTE system during ST.

Scenario	Description	LTE network performance
BALANCED	The anticipated LTE network-wide loading in SS bands, when deployed by an incoming user; Presumes all UEs can tune to the SS band(s) and the LTE network scheduler chooses to *uniformly* spread traffic across *all* available network RBs.	Models a *reactive* LTE deployment – i.e., LTE is deployed in response to there being a critical mass of SS-compatible UEs present to achieve an improvement to the equal share of network resources available per UE.
UNDERLOADED	There is *less* LTE traffic in SS bands than expected based upon the average network-wide load for an incoming LTE network.	Represents a *proactive* LTE deployment where SS bands are added to the LTE network *before* there are enough new UEs deployed to uniformly schedule traffic across *all* the LTE bands – traffic loading may be higher in other LTE bands where non-SS UEs have access to fewer RBs per UE.
OVERLOADED	LTE network traffic in SS bandwidth is *greater than* the average network-wide traffic load.	A hypothetical scenario of how the load in the SS band would increase if new UEs were *forced* to use the SS band – UEs forced into SS-bands would have fewer RBs per UE.

Tools for Spectrum Planning and Decision Making

- Policies for incoming and outgoing users can determine acceptable network operating parameters for reliable service.
  - How many UEs can utilize the SS band without interfering with critical services from outgoing users or incoming LTE users?
- Outgoing users can plan around how much LTE traffic they will be contending with in SS bands.
  - How will interference growth over time impact existing services?
- Operators can forecast *how* and *when* network deployment can impact performance or cost targets.
  - How many SS-compatible UEs should be deployed in an area to justify the CAPEX of SS deployment?

1. NTIA. (2013, Feb 21). Commerce Spectrum Management Advisory Committee Working Group 1 Final Report (v2).
   Available from: https:/www.ntia.doc.gov/other-publication/2013/csmac-wg-1-final-report-v2
2. Ray, N. (2016, Oct. 21) The Un-relenting Un-carrier Network, T-Mobile.
3. Alleven, M. (2018, Mar. 8) Verizon prepares for tests of new LTE equipment using AWS-3 Band 66, FierceWireless.
4. Lella, A. (2017, Apr 19). U.S. iPhone Ownership Reaches All-Time High on Strength of iPhone 7.
   Available from: https:/www.comscore.com/Insights/Blog/US-iPhone-Ownership-Reaches-All-Time-High-on-Strength-of-iPhone-7
5. Levin, M. and Lowitz, J. (2017, May 5). iPhone US Installed Base Growth Slows.
   [PDF document]. Retrieved from: http:/files.constantcontact.com/150f9af2201/951bd5fb-7410-4d08-a403-084f0cec482e.pdf

Challenges

- Any *Spectrum Sharing* (SS) between users during ST must ensure that *both* incoming and outgoing services can *co-exist*.
  - *How* should SS be used to support ST? – e.g.,
    - *When* should SS be used during a transition?
    - *How long* should SS be utilized during the transition?

Solution Approach

Model interference to outgoing users based on the incoming users' traffic

1. Utilize market data and demographics to estimate LTE loading.
2. Model wireless carrier and subscriber behavior over time – e.g.,
   - Carrier spectrum deployment behavior
     - Does LTE end User Equipment (UE) support the new band (yet)?
     - Where, geographically, can carriers offer service in the new band?
   - Consumer UE upgrade (and retirement) behavior
     - *How many* UEs – e.g., smartphones – will come online?
     - *When* will new UEs start showing up?
3. Create a network loading forecast for the LTE network.

Forecasting Methodology for LTE Traffic in Spectrum Sharing Bands

Simplifying assumptions

- The following modeling assumptions enable the use of *average LTE traffic* to forecast its evolution with *minimal information* about the incoming LTE network:
  - All UEs generate the same amount of traffic.
  - The LTE system's goal is to *maximize* resources available to each UE.
  - SS-compatible UE deployment is based upon *historical* survey data[4,5] from the launch of the iPhone 6 in the U.S.

Resource availability effects on LTE network performance

- *Resource availability* measures the average RBs available to any given UE.
  - Measured in units of *RBs per UE*.
- Higher resource availability is perceived to *improve* network performance for subscribers, as there are more RBs available at any given time for use.
  - The simplified assumption that *maximizing* the resource availability across the network implies an ideal case is where each UE has an opportunity to access an equal share of all network resources – represented by the *balanced* scenario (see case study on left).

Estimating LTE network loading

- The *network-wide* loading, $\hat{\iota}$, with SS bandwidth – i.e., dotted line in case study, on left – can be estimated by scaling the current network load based upon the total resources available after SS;

$$\hat{\iota} = \frac{\iota \cdot N_{\mathrm{RB,existing}}}{N_{\mathrm{RB,existing}} + N_{\mathrm{RB,ss}}}$$

  - ι represents the network-wide loading *before* SS bandwidth is deployed.
  - $N_{\mathrm{RB,existing}}$ is the network bandwidth – expressed in RBs – *before* SS.
  - $N_{\mathrm{RB,ss}}$ is the number of RBs added through SS.
- Short-term *loading estimates* in the *SS band* take into account the number of SS-compatible UEs and LTE network loading conditions *before* ST and SS:

$$\hat{\iota}_{\mathrm{ss}} = \iota \cdot \frac{N_{\mathrm{RB,existing}}}{d} \cdot \frac{d_{\mathrm{ss}}}{N_{\mathrm{RB,ss}}}$$

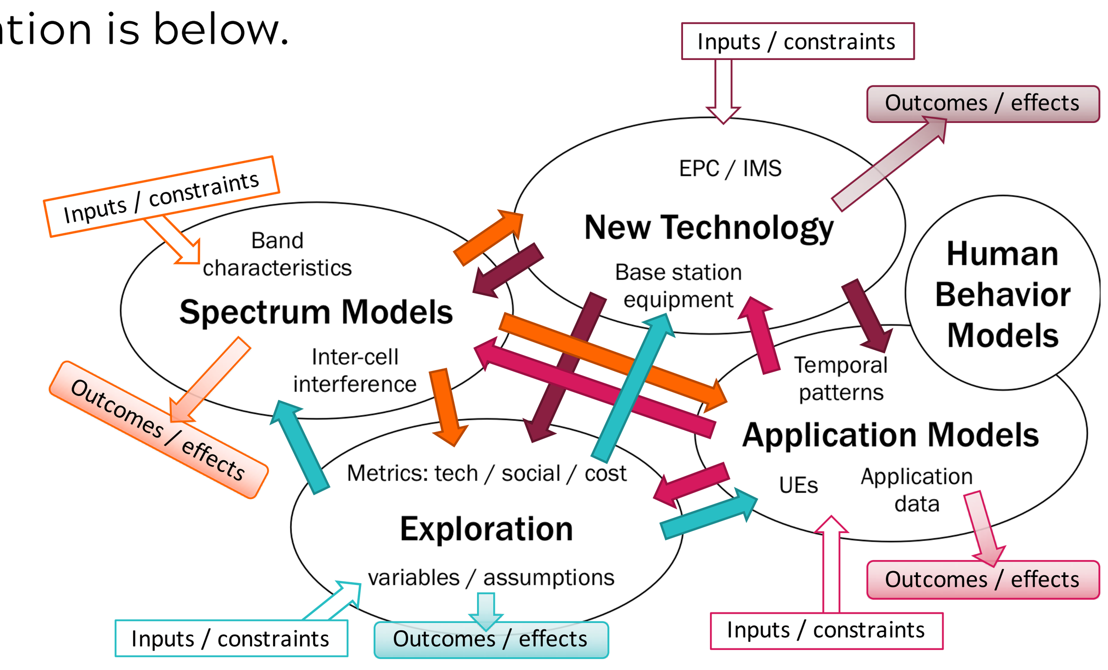
  - $\hat{\iota}_{\mathrm{ss}}$ is the estimated load in the SS band – i.e., shaded areas in case study, on left – where
    d: the *total* number of UEs (*before* SS), and
    d_{ss}: number of SS-compatible UEs deployed.

Continuing R&D

Traffic forecasting is but *one* aspect of our ST R&D; When utilized in conjunction with complementary R&D such as

- LTE emissions simulation,
- 5G technology capability models, and
- human mobility models

the traffic evolution model enables deeper exploration of ST inputs, effects, and outcomes – and a framework illustrating integrated ST and SS exploration is below.



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