D2D Communications under LTE-U System: QoS and Co-existence Issues are Incorporate

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- MNOs and SPs are availing great business amenities due to the thriving infiltration of wirelessly connected devices and multimedia rich applications
- Mobile data traffic has already grown exponentially and ¾ of that will be video in 2020[1]
- So, to combat with this challenge, MNOs need to increase the capacity of the RANs
- But with the limited licensed spectrum, it is a bottleneck for the MNOs
- Following this, new technologies like LTE-A, MIMO, D2D communication, cooperative communication are coming onward

[1] Cisco, Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update 2015 - 2020, White Paper, 2016.

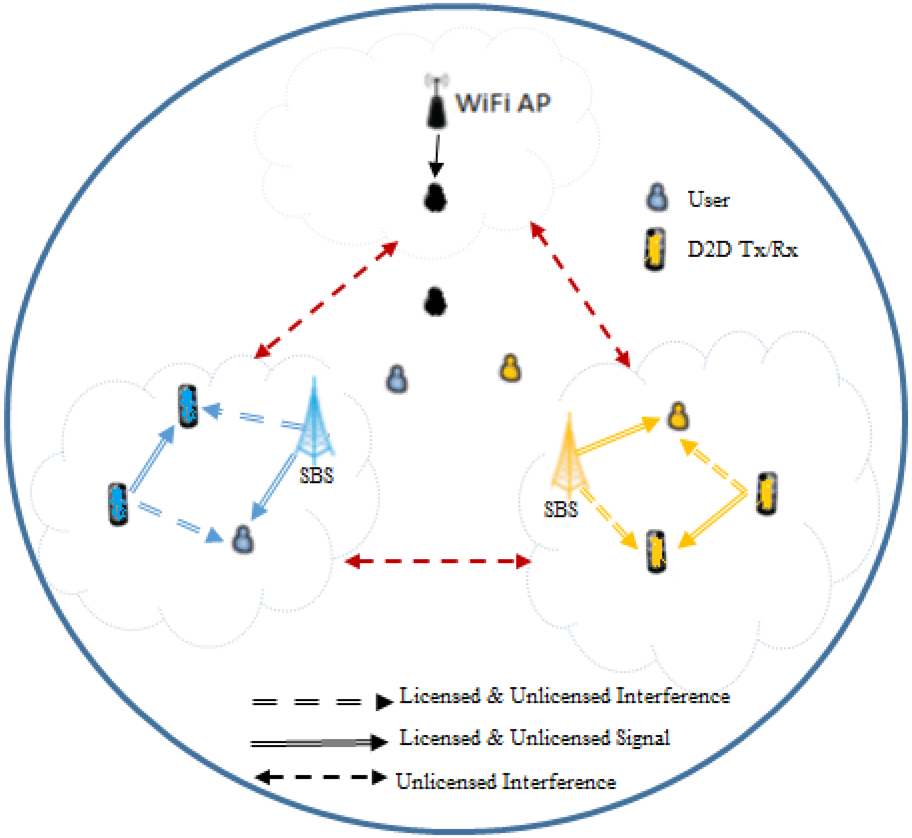
Introduction (Cont..)

- But this steps are inadequate to provide guaranteed services to the users with limited resources
- So, MNOs are offloading part of their traffic by engaging WAPs
- But, Wi-Fi technology is not efficient dealing with more users and guaranteed data rate
- Thus, peoples are focusing of utilizing unlicensed spectrum with LTE network
- D2D communication has also shown increasing spectral efficiency and combing these two can further increase the efficiency
- But co-existence with WAPs is the main challenge for these aggregating efforts

Introduction (Cont..)

- There are several proposals for fair co-existing of these two networks, but very few of them considers inter-operator's issue regarding this problem
- Furthermore, there are very few proposal that combines D2D with LTE-U
- So, in this paper, we superintend the underlaid D2D communications to LTE-U system considering the QoS requirements of the users and D2D pairs while protecting WAPs from ruining

System Model and Problem Formulation



- A set of dual of dual-mode LTE-A SBSs, $S=\{1,2,..,S\}$
- A set of WAPs, $W=\{1,2,..,W\}$
- Each SBS users $U_i = \{1,2,...,N_i\}$ and D2D pairs $D_i = \{1,2,...,M_i\}$

- A. Achievable Rate of LTE-U user and D2D pair
  - Rate in Licensed Spectrum:
    - Achievable rate of LTE-U user j in sub-channel k:

$$R_{i,j}^{l,k} = B_l log_2(1 + \frac{x_{i,j}^k P_i^c |g_{i,j}^k|^2}{\sum_{m \in D_i} y_{i,m}^k P_i^d |g_{m_t,j}^k|^2 + \sigma^2}) \quad (1)$$

    - Achievable rate of D2D pair m over sub-channel k:

$$R_{i,m}^{l,k} = B_l log_2(1 + \frac{y_{i,m}^k P_i^d |g_{m_t,m_r}^k|^2}{\sum_{j \in U_i} x_{i,j}^k P_i^c |g_{i,m_r}^k|^2 + \sigma^2}) \quad (2)$$

  - Rate in Unlicensed Spectrum:
    - Achievable rate of user j and D2D pair m respectively in sub-channel k':

$$R_{i,j}^{u,k'} = B_u log_2(1 + \frac{x_{i,j}^{k'} P_i^c |g_{i,j}^{k'}|^2}{I_{S \setminus i}^c + I_S^d + I_W + \sigma^2}) \quad (3)$$

$$R_{i,m}^{u,k'} = B_u log_2(1 + \frac{y_{i,m}^{k'} P_i^d |g_{m_t,m_r}^{k'}|^2}{I_S^c + I_{S \setminus i}^d + I_W + \sigma^2}) \quad (4)$$

- A. Achievable Rate of LTE-U user and D2D pair (Cont..)
  - Interference to user caused by users of other MNOs:

$$I^c_{S\backslash i} = \sum_{s=1,s\neq i}^{S} \sum_{n\in U_s} x^{k'}_{s,n} P^c_s |g^{k'}_{s,j}|^2$$

  - Interference caused by D2D pairs:

$$I^d_S = \sum_{s\in S} \sum_{m\in D_s} y^{k'}_{s,m} P^d_s |g^{k'}_{m_t,j}|^2$$

  - Interference to D2D pair caused by users:

$$I^c_S = \sum_{s\in S} \sum_{n\in U_s} x^{k'}_{s,n} P^c_s |g^{k'}_{s,m_r}|^2$$

  - Interference to D2D pair caused by D2D pairs of other MNOs:

$$I^d_{S\backslash i} = \sum_{s\in S,s\neq i} \sum_{m'\in D_s} y^{k'}_{s,m'} P^d_s |g^{k'}_{m'_t,m_r}|^2$$

  - But study [9] shows that Wi-Fi affects negligibly to the LTE-U
  - Moreover, in dense deployment

$$I^c_{S\backslash i} + I^d_S >> P^u_i |g^{k'}_{i,j}|^2 \text{ and } I^c_S + I^d_{S\backslash i} >> P^d_i |g^{k'}_{m_t,m_r}|^2$$

[9] A.M. Cavalcante et al., Performance evaluation of LTE and WI-FI coexistence in unlicensed bands, In Proceedings of IEEE Vehicular Technology Conference (VTC Spring), pages 1-6, Dresden, Germany, June 2013.

- A. Achievable Rate of LTE-U user and D2D pair (Cont..)
  - So, to take advantage over unlicensed spectrum, SBSs can form grand coalition and split this resources in orthogonal fashion

$$SC^u = SC_1^u \cup SC_2^u \cup \ldots \cup SC_S^u \text{ where } SC_i^u \cap SC_j^u = \emptyset$$

  - Thus, the achievable rate of LTE-U user and D2D pair are as follows:

$$R_{i,j}^{u,k'} = B_u log_2(1 + \frac{x_{i,j}^{k'} P_i^c |g_{i,j}^{k'}|^2}{\sum_{m \in D_i} y_{i,m}^{k'} P_i^d |g_{m_t,j}^{k'}|^2 + \sigma^2}) \quad (5)$$

$$R_{i,m}^{u,k'} = B_u log_2(1 + \frac{y_{i,m}^{k'} P_i^d |g_{m_t,m_r}^{k'}|^2}{\sum_{n \in U_i} x_{i,n}^{k'} P_i^c |g_{i,m_r}^{k'}|^2 + \sigma^2}) \quad (6)$$

- B. Data Rate of Wi-Fi
  - The average achieved rate of a single Wi-Fi user:

$$R_w = \frac{R_W}{W} \quad (7)$$

  - If we consider SBSs act like WAP then the rate becomes [18]:

$$R_w^{min} = \frac{P_{tr'} P_{s'} E[P](W+S)^{-1}}{(1-P_{tr'})T_\sigma + P_{tr'} P_{s'} T_s + P_{tr'}(1-P_{s'})T_c} \quad (8)$$

  - Thus, when SBSs want to use same unlicensed band, they must have to maintain at least R_w^{min} rate for a Wi-Fi user

[18] G. Bianchi, Performance analysis of the IEEE 802.11 distributed co-ordination function. IEEE Journal on selected areas in communications, 18(3):535-547, March 2000.

- C. Problem Formulation
  - For fair co-existence of WAPs and SBSs in the same unlicensed band, it is necessary to share time slot
  - Lets, SBSs share $t \in [0,1]$ time slot with WAPs
  - Then, the achievable rates:

$$R_w^t = R_w * t \quad (9)$$

$$R_{i,j}^t = \sum_{k \in SC_i} x_{i,j}^k R_{i,j}^{l,k} + (1-t) * \sum_{k' \in SC_i^u} x_{i,j}^{k'} R_{i,j}^{u,k'} \quad (10)$$

$$R_{i,m}^t = \sum_{k \in SC_i} y_{i,j}^k R_{i,m}^{l,k} + (1-t) * \sum_{k' \in SC_i^u} y_{i,j}^{k'} R_{i,m}^{u,k'} \quad (11)$$

- C. Problem Formulation (Cont..)
  - Now our goal is to develop an efficient spectrum allocation scheme that will maximize the sum-rate of LTE-U users and D2D pairs
  - Thus, the optimization problem is as follows:

$$
\begin{aligned}
\max_{\boldsymbol{x},\boldsymbol{y},t} \quad & \sum_{i\in S}\left(\sum_{j\in U_i} R_{i,j}^t + \sum_{m\in D_i} R_{i,m}^t\right) \\
\text{s.t.} \quad & C_1: \sum_{j\in U_i} x_{i,j}^k \le 1, \sum_{m\in D_i} y_{i,m}^k \le 1, \forall k \in SC_i, \forall i \in S \\
& C_2: \sum_{j\in U_i} x_{i,j}^{k'} \le 1, \sum_{m\in D_i} y_{i,m}^{k'} \le 1, \forall k' \in SC_i^u, \forall i \in S \\
& C_3: \sum_{k\in SC_i} x_{i,j}^k \ge 1, \sum_{k\in SC_i} y_{i,m}^k \ge 1, \forall j \in U_i, \forall m \in D_i \\
& C_4: x_{i,j}^k, y_{i,m}^k \in \{0,1\}, \forall k, \forall j \in U_i, \forall m \in D_i, \forall i \in S \\
& C_5: R_{i,j}^t \ge QoS_{i,j}, R_{i,m}^t \ge QoS_{i,m}, \exists j, m, \forall i \in S \\
& C_6: R_w^t \ge R_w^{min}, \forall w \in W, t \in [0,1]
\end{aligned} \tag{12}
$$

  - Optimization (12) is MINLP problem and NP-hard

Solution with Bargaining Game

- Bargaining game is a typical cooperative game for fair resource allocation
- We have player: $P = \{W, S\}$
- Utilities of players:

$$U_W = \sum_{w \in W} R_w^t$$

$$U_S = \sum_{i \in \mathbf{S}} (\sum_{j \in U_i} (R_{i,j}^t - \sum_{k \in SC_i} x_{i,j}^k R_{i,j}^{l,k}) + \sum_{m \in D_i} (R_{i,m}^t - \sum_{k \in SC_i} y_{i,j}^k R_{i,m}^{l,k}))$$

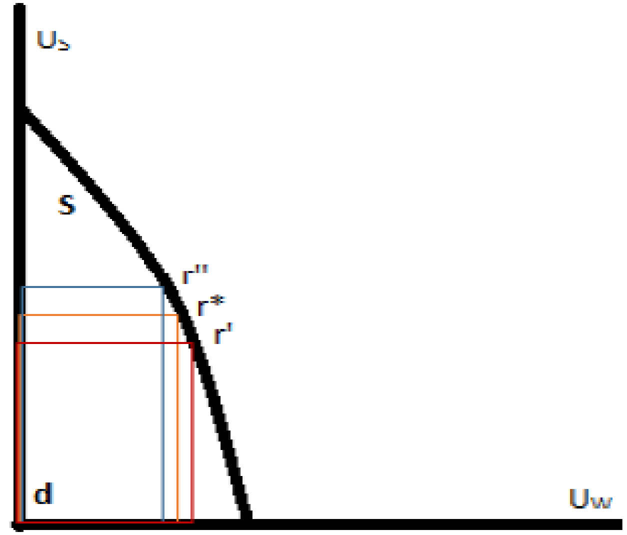


Fig. 2: NBS in two players' game

- A. Nash Bargaining Solution

Theorem 1: There exists a unique solution concept $\phi(\mathbf{S}, \mathbf{d})$ that satisfies all six axioms of Definition 2 and it follows [19]

$$r^* = \phi(\mathbf{S}, \mathbf{d}) \in argmax_{\mathbf{r} \in \mathbf{B}} \prod_{i=1}^{|P|} (r_i - d_i) \qquad (13)$$

Without sacrificing generality, another equivalent expression of (13) can be formulated using logarithm as follows:

$$r^* = argmax_{\mathbf{r} \in \mathbf{B}} \sum_{i=1}^{|P|} \ln(r_i - d_i) \qquad (14)$$

Theorem 2: The point in bargaining set **B** which satisfies just the minimum rate (R_w^{min}) requirement of WAPs is the solution of Nash bargaining game.

[19] M. Maschler, E. Solan and S. Zamir, Game Theory, Cambridge University Press, New York, 2013.

Solution with Bargaining Game (Cont..)

- B. Algorithm using NBS

Algorithm 1 Cooperated Unlicensed Spectrum Utilization among SBSs of different MNOs

1: Initialization: Set of WiFi APs W and set of SBSs S
2: Each $i \in S$ distributes licensed spectrum among it's users and D2D pairs based upon constraints C_1, C_3, C_5
3: Each $i \in S$ determines minimum QoS capacity gap of it's users and D2D pairs by $QG_i = \sum_{j \in U_i} max(QoS_{j,i} - R^l_{j,i}, 0) + \sum_{m \in D_i} max(QoS_{m,i} - R^l_{m,i}, 0)$
4: Each $i \in S$ senses the active WAPs in the conflicting area
5: Every member of S exchanges that information to form a grand coalition and one SBS acts as an arbitrator
6: Arbitrator determines the bargaining set $\mathbf{B}$ depending upon the received information from all SBSs
7: Finds $r^* \in argmax_{\mathbf{r} \in \mathbf{B}} \prod_{\forall k \in P} r_k$ considering $\mathbf{d} = (0, 0)$
8: Finds $t \in [0, 1]$ from r^* during which SBSs will not operate in unlicensed band satisfying constraint C_6
9: Arbitrator finds $N_i^u = \frac{QG_i}{\sum_{j \in S} QG_j} C_u, \forall i \in S$ denoted by set $SC_i^u = \{1, 2, ..., N_i^u\}$ to allocate unlicensed resources to the SBSs and inform them with frequency to use it in $1 - t$ time slot
10: Each SBS $i \in S$ allocates SC_i^u among it's users and D2D pairs based upon their minimum QoS capacity gap to use with licensed spectrum using CA to reduce this gap or to meet the requirement with satisfying constraints C_2, C_5.

Performance Evaluation

- We have taken 5 SBS and 5 WAP
- Each SBS has 25 users and 25 D2D pairs

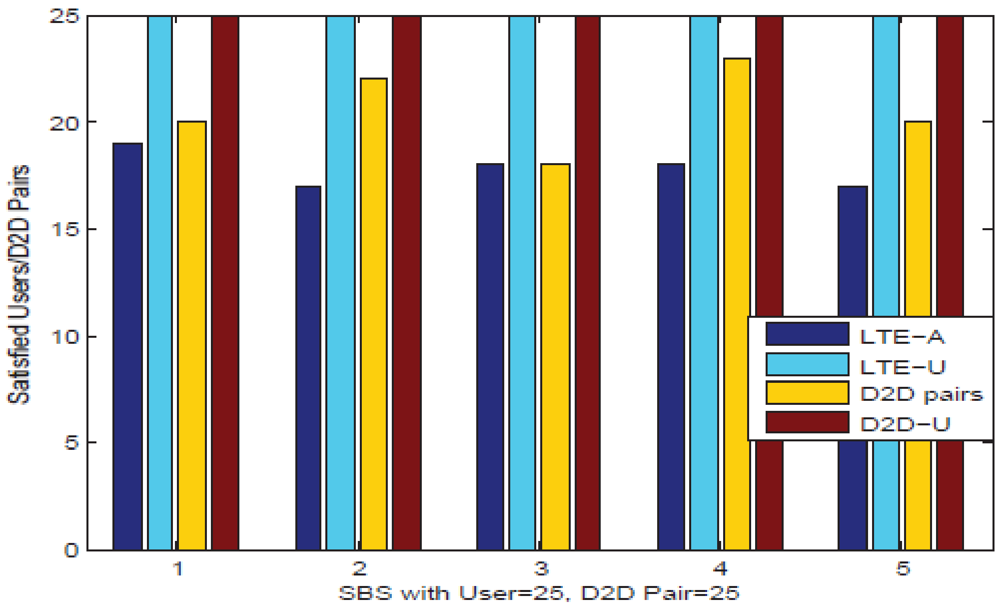


Fig. 3: Comparison of QoS Satisfied User/D2D pairs in each SBS

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Performance Evaluation

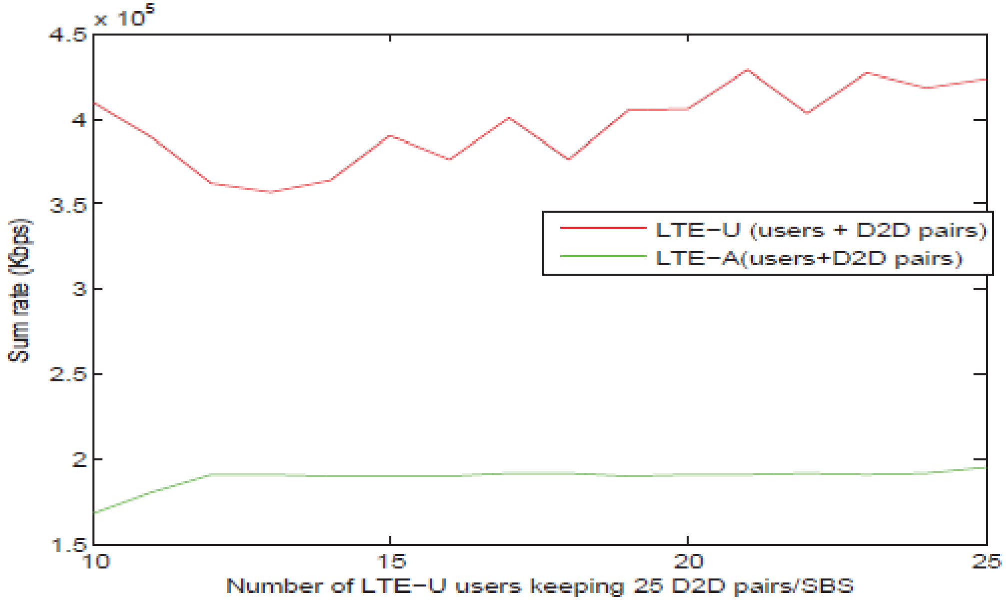

Fig. 4: Sum Rate of all SBSs

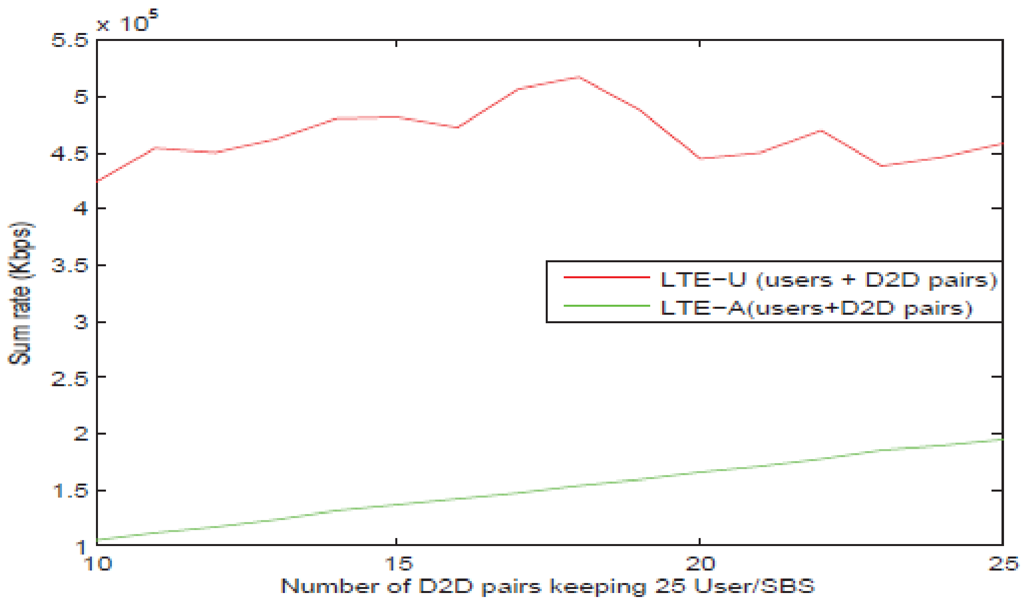

Fig. 5: Sum Rate of all SBSs with varying number of D2D pairs

Conclusion

- In this paper, we have superintended D2D communication with LTE-U system where D2D pairs work as an underlay to the LTE-U network

- We have fixed the co-existence issue with the help of NBG between SBSs and WAPs

- Proposed system can provide better QoS and also sum-rate than traditional LTE-A

Thanks
Q&A