ISSN: 2277-9655
(I2OR), Publication Impact Factor: 3.785
(ISRA), Journal Impact Factor: 2.114

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

OFDMA RELAY NETWORKS FOR PERFORMING MULTICAST OPERATIONS

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ABSTRACT

The two-hop orthogonal frequency-division multiple access (OFDMA) relay networks have become a dominant, mandatory component in the 4G standards (WiMAX 802.16j, 3GPP LTE-Adv). While unicast flows have received reasonable attention in two-hop OFDMA relay networks, not much light has been shed on the design of efficient scheduling algorithms for multicast flows. Given the growing importance of multimedia broadcast and multicast services (MBMS) in 4G networks. We show that while relay cooperation is critical for improving multicast performance, it must be carefully balanced with the ability to multiplex multicast sessions and hence maximize aggregate multicast flow. To this end, we highlight strategies that carefully group relays for cooperation to achieve this balance. We then solve the multicast scheduling problem under two OFDMA subchannelization models. We establish the NP-hardness of the scheduling problem even for the simpler model and provide efficient algorithms with approximation guarantees under both models. Evaluation of the proposed solutions reveals the efficiency of the scheduling algorithms as well as the significant benefits obtained from the multicasting strategy.

KEYWORDS: Orthogonal frequency division multiple access (OFDMA), relay cooperation, scheduling, session multiplexing, wireless multicast.

INTRODUCTION

The next-generation wireless networks moving toward smaller (micro, pico) cells for providing higher data rates, there is a revived interest in multihop wireless networks from the perspective of integrating them with cellular networks. With a decrease in cell size, relay stations (RS) are now needed to provide extended coverage. In this context, *two-hop relay-enabled* wireless networks [Fig. 1(a)] have become a dominant, mandatory component in the 4G standards. Orthogonal frequency-division multiple access (OFDMA) has become the popular choice for air interface technology in 4G networks. The entire spectrum is divided into multiple carriers (subchannels), allowing for multiple users to operate in tandem. This leads to several physical-layer and scheduling benefits [3], [4]. The two-hop network model coupled with OFDMA provides several diversity (multiuser, channel, and cooperative) gains that can be leveraged through intelligent scheduling. While several scheduling works [5]–[7] have focused on unicast traffic for two-hop OFDMA relay networks, multicast traffic has not been explored much in these networks.

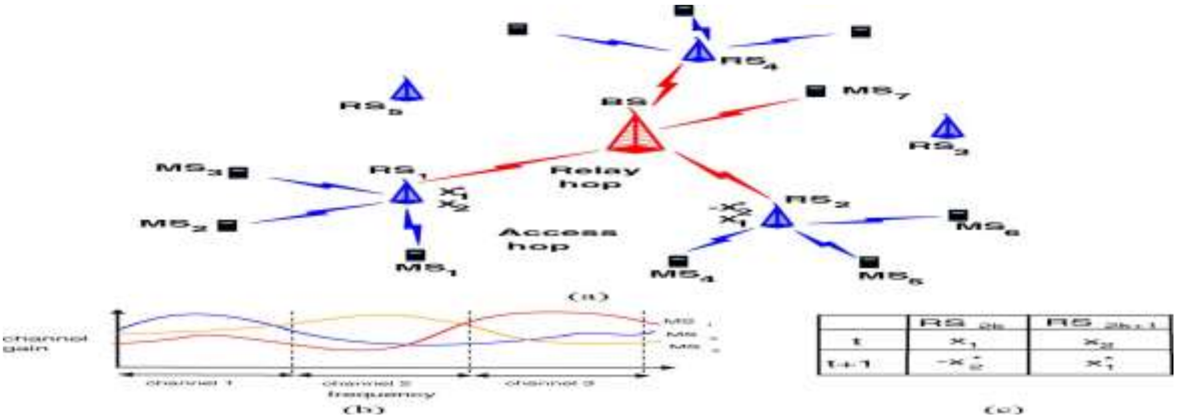


Fig. 1 System model and gains. (a) Network model. (b) User/channel diversity. (c) Relay cooperation.

Multicasting in two-hop relay networks is significantly different from the conventional cellular multicast: The broadcast advantage of multicast data is significantly diminished on the access (second) hop [Fig. 1(a)], where they become equivalent to multiple unicast transmissions from different RS to mobile stations (MS), thereby requiring more transmission resources. Relay cooperation mechanisms allow multiple RS to simultaneously transmit the multicast data on the same transmission resource.

The key question, however, is the following: *Is relay cooperation always beneficial?* Interestingly, we show that there exists a subtle trade-off between cooperation gains and the ability to multiplex multicast sessions effectively, both of which are essential for maximizing the aggregate multicast system performance. In the process, motivated by recent relay standards [1], [2], [9], we consider two models for how subcarriers are grouped to form a subchannel in OFDMA[10]: *distributed* (DP) and *contiguous* (CP) permutations. Our contributions in this paper are multifold.

- We highlight and address the trade-off between cooperation gain and effective multiplexing of multicast sessions through intelligent grouping of relays for cooperation.
- We provide LP-based algorithms with guarantees of max {1/2,(1-c(c-1)/2N)} for the DP model, and $\left(1-\frac{1}{e}-\epsilon\right)^c$ for the harder CP model. Where c<=R+1 is a small constant; N ,R are the number of channels and relays.
- We also provide efficient, fast greedy algorithms for both the models, whose performance is very close to that of their LP-based algorithms.

SYSTEM ARCHITECTURE

A. Network Model

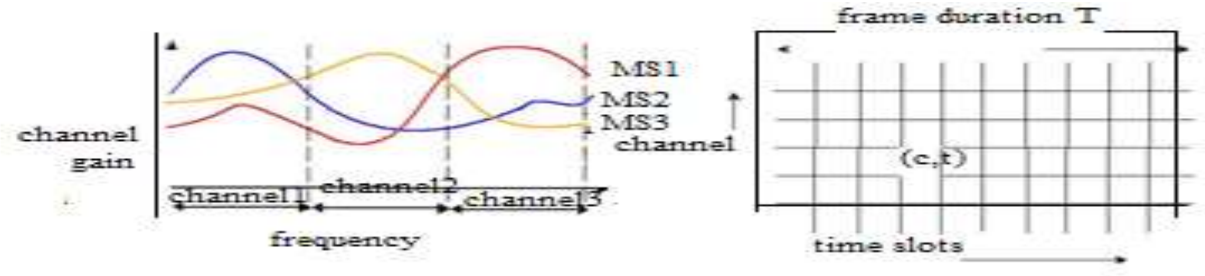
We consider a downlink OFDMA-based, relay-enabled, two-hop wireless network [10] as shown in Fig. 1(a). A set of MS are uniformly located within the macro cell. A small set of RS are added to the midway belt of the network. MS farther from the base station (BS) connect with the RS that is closest to them based on highest signal-to-noise ratio (SNR). The one-hop links between BS and RS are referred to as *relay links*, between RS and MS as *access links*, and between BS and MS as *direct links* (equivalent to relay links for scheduling purposes).The total OFDM subchannels is considered, with two models for grouping of subcarriers to form a subchannel [1]:*distributed permutation* (DP) and *contiguous permutation* (CP).

B. Scheduling Model

Frame Structure: We consider a synchronized, time-slotted system (WiMAX, LTE) with BS and RS transmitting data in frames. Every frame consists of several time-slots and has to be populated with user assignments across channels for LTE (no channel sharing across slots) and user assignments across both time-slots and channels for WiMAX as shown in Fig 2(b). To address both models generically, it is sufficient to consider the problem with one time-slot per frame since channels in other time-slots can be considered as additional channels available to the time-slot under consideration.

The entire spectrum is divided into multiple carriers (sub-channels), leading to several physical layer and scheduling benefits [3], [4]. The two-hop network model coupled with OFDM provides two key benefits, namely *diversity* and *spatial reuse* gains.

Three kinds of diversity gains can be exploited through scheduling as shown in Fig 2(a): (i) *multi-user diversity*: for a given subchannel, different users experience different fading statistics, allowing us to pick a user with a larger gain; (ii) *channel diversity*: subchannels experiencing high gain could vary from one user to another, allowing for multiple users to be assigned their best channels in tandem; and (iii) *cooperative diversity*: relays can exploit wireless broadcast advantage to cooperate and improve the SNR (signal-noise ratio) at the intended receiver. In addition to the diversity gain, the two-hop network model also provides room for *spatial reuse*, whereby simultaneous transmissions on the relay hop (BS-RS) and access hop (RS-MS) can be leveraged on the same channel as long as there is no mutual interference.

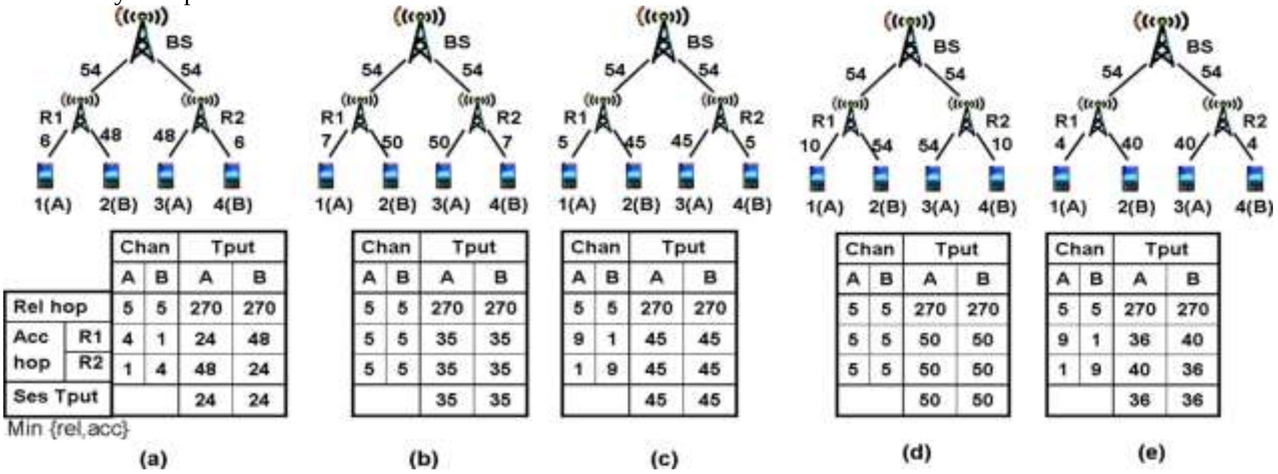


(a) (b)

Fig. 2. Network Model a)Multi-user and Channel Diversity b)Frame Structure

C. Multicasting Strategy

While relay cooperation is critical for multicast, the key question, however, is the following: *Is relay cooperation always beneficial?* Interestingly, there exists a subtle trade-off between cooperation gains and the ability to multiplex multicast sessions effectively, both of which are essential for maximizing the aggregate multicast system performance.



(a)

		Chan		Tput	
		A	B	A	B
Rel hop		5	5	270	270
Acc hop	R1	4	1	24	48
	R2	1	4	48	24
Ses Tput				24	24

(b)

Chan		Tput	
A	B	A	B
5	5	270	270
5	5	35	35
5	5	35	35
		35	35

(c)

Chan		Tput	
A	B	A	B
5	5	270	270
9	1	45	45
1	9	45	45
		45	45

(d)

Chan		Tput	
A	B	A	B
5	5	270	270
5	5	50	50
5	5	50	50
		50	50

(e)

Chan		Tput	
A	B	A	B
5	5	270	270
9	1	36	40
1	9	40	36
		36	36

Fig. 3 Trade-off illustration

Consider the following example with two sessions and 10 channels on each hop (Fig. 3). Users 1, 3 belong to session, while 2, 4 belong to session. The DP model is considered, where the transmission rate to a user (or relay) per channel does not vary across channels and are directly assumed as indicated in Fig. 3(a) on the relay and access hops for a single channel. Note that the purpose of this example is to merely highlight the trade-off the actual magnitude of the gains resulting from addressing the trade-off would in turn depend on various factors such as channel model, transmission power, etc. Furthermore, with relay-hop rates being significantly higher than the access-hop rates in our example, the access hop forms the bottleneck, whose performance consequently depends on the scheduling strategy employed.

EXISTING SYSTEM

With the next-generation wireless networks moving toward smaller (micro, pico) cells for providing higher data rates, there is a revived interest in multihop wireless networks from the perspective of integrating them with cellular networks. With a decrease in cell size, relay stations (RS) are now needed to provide extended coverage. In this context, two-hop relay-enabled wireless networks have become a dominant, mandatory component in the 4G standards (WiMAX 802.16m, 3GPP LTE-Adv) due to the plethora of envisioned applications (hotspots, office buildings, underground tunnel access, etc.) they support. The drawbacks are it returns a single channel quality value and there is no multicast scheduling.

PROPOSED SYSTEM

Evaluation of the proposed solutions reveals the efficiency of the scheduling algorithms as well as the significant benefits obtained from the multicasting strategy. We evaluate the proposed solutions in an event-driven simulator that incorporates realistic physical-layer effects. We considered the problem of multicast scheduling in two-hop OFDMA relay networks. We showed that intelligent grouping of relays for cooperation is needed to address the tradeoff between cooperation and session multiplexing gains. We designed efficient scheduling algorithms at core of the multicast strategy to address the tradeoff and maximize aggregate multicast flow. The advantages of proposed system are there is multicast scheduling and multiuser diversity.

RELATED WORK

(IEEE 802.16m 2011 Part 16, May 2011) Orthogonal frequency-division multiple access (OFDMA) has become the popular choice for air interface technology in 4G networks. IEEE 802.16m, IMT-Advanced radio interface, WirelessMAN-Advanced Air Interface, wireless metropolitan area networks *IEEE 802.16m 2011 Part 16, Air Interface for Broadband Wireless Access Systems—Advanced Air Interface*, IEEE 802.16m, May 2011 this amendment specifies the WirelessMAN-Advanced Air Interface, an enhanced air interface designated as "IMT-Advanced" by the International Telecommunication Union—Radiocommunication Sector (ITU-R). The amendment is based on the Wireless MAN-OFDMA specification and provides continuing support for legacy subscriber stations.

Wireless systems for achieving high speed mobile wireless access services can be divided into two groups. The first group is International Mobile telecommunications-2000 [IMT-2000]. The second group consists of IEEE 802.16e, IEEE 802.16j, and IEEE 802.16m standard specified by IEEE 802.16 committee.

The second group is also called as Worldwide interoperability for Microwave access (WiMAX) standard is one of the 4G (4th generation) telecommunication technologies that supplies wireless communication of data through different transmission links like point to multi point.

(3GPP, "Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description," TS 36.300, Sep. 2012.) The E-UTRAN consists of eNBs, providing the E-UTRA user plane (PDCP/RLC/MAC/PHY) and control plane (RRC) protocol terminations towards the UE. The eNBs are interconnected with each other by means of the X2 interface. The eNBs are also connected by means of the S1 interface to the EPC(Evolved Packet Core), more specifically to the MME(Mobility Management Entity) by means of the S1-MME and to the Serving Gateway (S-GW) by means of the S1-U. The S1 interface supports a many-to-many relation between MMEs / Serving Gateways and eNBs.

(Z.Zhang, Y.He , and K.P. Chong, Mar. 2005.) Opportunistic scheduling exploits the time-varying, location-dependent channel conditions to achieve multiuser diversity. Previous work in this area has focused on single-channel systems. Multiuser OFDM allows multiple users to transmit simultaneously over multiple channels. We develop a rigorous framework to study opportunistic scheduling in multiuser OFDM systems. We derive optimal opportunistic scheduling policies under three QoS/fairness constraints for multiuser OFDM systems—temporal fairness, utilitarian fairness, and minimum performance guarantees. Our scheduler decides not only which time slot, but also which subcarrier to allocate to each user. We derive our opportunistic scheduling policies under three long-term QoS/fairness constraints—temporal fairness, utilitarian fairness, and minimum-performance guarantees, which are similar in form to those of, but adapted to the setting of multiuser OFDM systems.

(G. Song and Y. Li, Mar. 2005.) Provide a theoretical framework for cross-layer optimization for orthogonal frequency division multiplexing (OFDM) wireless networks. The utility is used in our study to build a bridge between the physical layer and the media access control (MAC) layer and to balance the efficiency and fairness of wireless resource allocation. We formulate the cross-layer optimization problem as one that maximizes the average utility of all active users subject to certain conditions, which are determined by adaptive resource allocation schemes. Numerical results demonstrate a significant performance gain for the cross-layer optimization and the gain increases with the number of active users in the networks.

(A.Hottinen and T.Heikkinen, Mar. 2006.) A source-relay-destination link in which the relay node is allowed to reassign the input subchannels to different output subchannels. In particular, we consider a channel-aware relay node and compute the subchannel reassignment that optimizes a selected performance criterion. The numerical results suggest that optimized subchannel reassignment is particularly beneficial in frequency-selective channels and in channels where interference information is available at transmitter.

ALGORITHMS

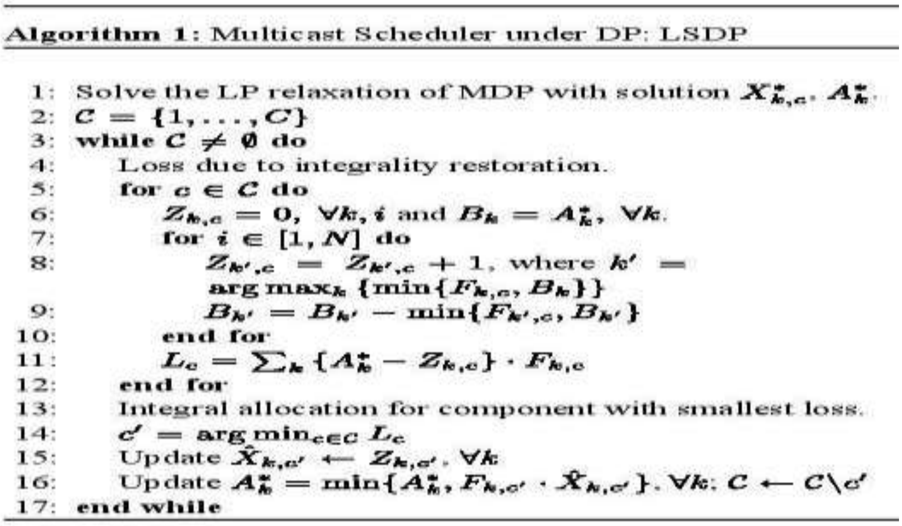
We propose the two scheduling algorithms for multicast scheduling which is based on efficient scheduling algorithm:

A.Multicast Scheduling Under DP

The design of efficient scheduling algorithms for multicast traffic forms a vital component of MBMS [10] and in turn forms the focus of this paper.

With distributed permutation, all channels of a session experience the same rate in a component (due to cooperation), but vary across components. The scheduling problem (MDP) can be formulated as the following integer program (IP).We propose the following linear program (LP)-based polynomial-time algorithm(LSDP) to solve MDP.

LSDP first solves the LP relaxation of MDP with Xk,c Ɛ [0,N (step1). Let the solution be X*k,c and Ak* with net optimal flow being ∑k Ak*. X*k,c gives the net fractional channel allocation to session k on component c, with ∑k X*k,c ≤. N However, some of the channels may be fractionally shared between sessions in each component, whose integrality needs to be restored for a feasible schedule. For each component c, we determine the loss due to integrality restoration (steps 4–12).



Algorithm 1: Multicast Scheduler under DP: LSDP

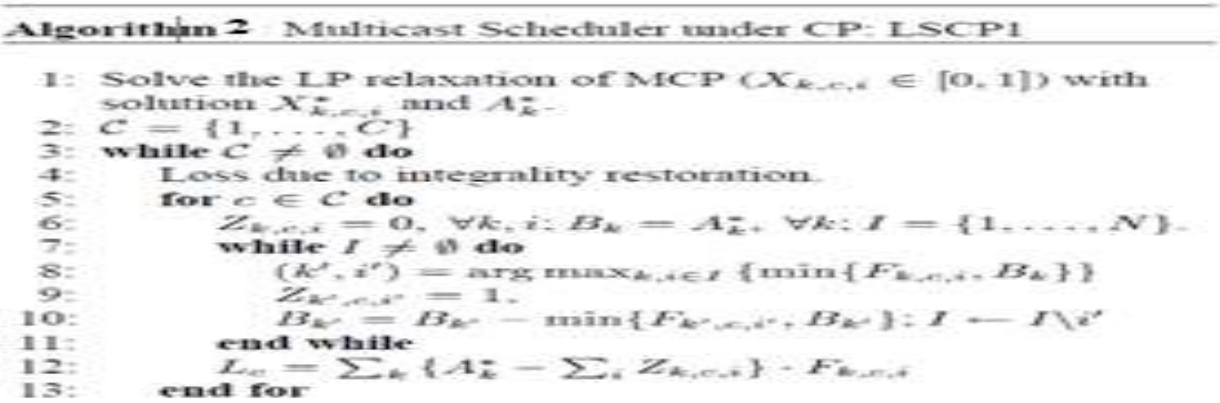
```
1:  Solve the LP relaxation of MDP with solution $X^*_{k,c}$, $A^*_k$.
2:  $\mathcal{C} = \{1, \dots, C\}$
3:  while $\mathcal{C} \neq \emptyset$ do
4:      Loss due to integrality restoration.
5:      for $c \in \mathcal{C}$ do
6:          $Z_{k,c} = 0, \forall k, i$ and $B_k = A^*_k, \forall k$.
7:          for $i \in [1, N]$ do
8:              $Z_{k',c} = Z_{k',c} + 1$, where $k' = \arg\max_k \{\min\{F_{k,c}, B_k\}\}$
9:              $B_{k'} = B_{k'} - \min\{F_{k',c}, B_{k'}\}$
10:         end for
11:         $L_c = \sum_k \{A^*_k - Z_{k,c}\} \cdot F_{k,c}$
12:     end for
13:     Integral allocation for component with smallest loss.
14:     $c' = \arg\min_{c \in \mathcal{C}} L_c$
15:     Update $\hat{X}_{k,c'} \leftarrow Z_{k,c'}, \forall k$
16:     Update $A^*_k = \min\{A^*_k, F_{k,c'} \cdot \hat{X}_{k,c'}\}, \forall k$; $\mathcal{C} \leftarrow \mathcal{C} \backslash c'$
17: end while
```

This requires a new integral channel allocation (Zk,c) for each component c. With Ak* as the maximum flow limit for session k, we assign each channel to the session yielding the largest flow in the component based on its remaining flow limit (steps 7–10). Alternately Zk,c, can be directly derived from X*k,c by removing only the required number of channel allocations with the smallest flow, thereby eliminating the dependence on N. The loss resulting from this integral allocation is then determined with respect to the optimal fractional allocation (step 11). The component yielding the smallest loss is chosen (c′), and the corresponding integral allocation (X̂k,c′) is determined (steps 13–16). The procedure is repeated until integral channel allocation is restored to all components.

B.Multicast Scheduling Under CP

Unlike the distributed permutation model, in contiguous permutation, channels of a session experience different rates both within and across components.

This makes the problem and the design of efficient algorithms significantly harder under CP.



Algorithm 2 Multicast Scheduler under CP: LSCP1

```
1:  Solve the LP relaxation of MCP ($X_{k,c,i} \in [0, 1]$) with solution $X^*_{k,c,i}$ and $A^*_k$.
2:  $\mathcal{C} = \{1, \dots, C\}$
3:  while $\mathcal{C} \neq \emptyset$ do
4:      Loss due to integrality restoration.
5:      for $c \in \mathcal{C}$ do
6:          $Z_{k,c,i} = 0, \forall k, i$; $B_k = A^*_k, \forall k$; $I = \{1, \dots, N\}$.
7:          while $I \neq \emptyset$ do
8:              $(k', i') = \arg\max_{k, i \in I} \{\min\{F_{k,c,i}, B_k\}\}$
9:              $Z_{k',c,i'} = 1$.
10:             $B_{k'} = B_{k'} - \min\{F_{k',c,i'}, B_{k'}\}$; $I \leftarrow I \backslash i'$
11:         end while
12:         $L_c = \sum_k \{A^*_k - \sum_i Z_{k,c,i}\} \cdot F_{k,c,i}$
13:     end for
```

```
    Integral allocation for component with smallest loss.
    $c' = \arg\min_{c \in C} L_c$
    Update $\hat{X}_{k,c',i} \leftarrow Z_{k,c',i}, \forall k, i$
    Update $A_k^* = \min\{A_k^*, \sum_i F_{k,c',i}\hat{X}_{k,c',i}\}$. $C \leftarrow C \backslash c'$
end while
```

Algorithm LSCP1 follows an approach similar to LSDP. It uses the fractional solution from solving the LP relaxation of MCP as the starting point and restores integrality in each component sequentially.

PERFORMANCE EVALUATION

An event-driven packet-level network simulator written in C++ coupled with the GNU LP kit is considered for evaluation of the proposed solutions. A single-cell relay-enabled OFDMA downlink system is considered, with a cell radius of 600 m. MS are uniformly distributed within the cell, while RS are distributed uniformly within a region of 250 m≤r≤350 m from the BS. The relay channel model proposed for the 802.16m standard [1] is considered and incorporates path loss, log-normal shadowing, and Rayleigh fading. Specifically, for the BS-RS links, we use the Type-D line-of-sight path-loss model that is recommended for the above-rooftop-to-above-rooftop urban links, while for the BS-MS and RS-MS links, we use the Type-E non-line-of-sight path-loss model that is recommended for the above-rooftop-to-below-roof top urban links.

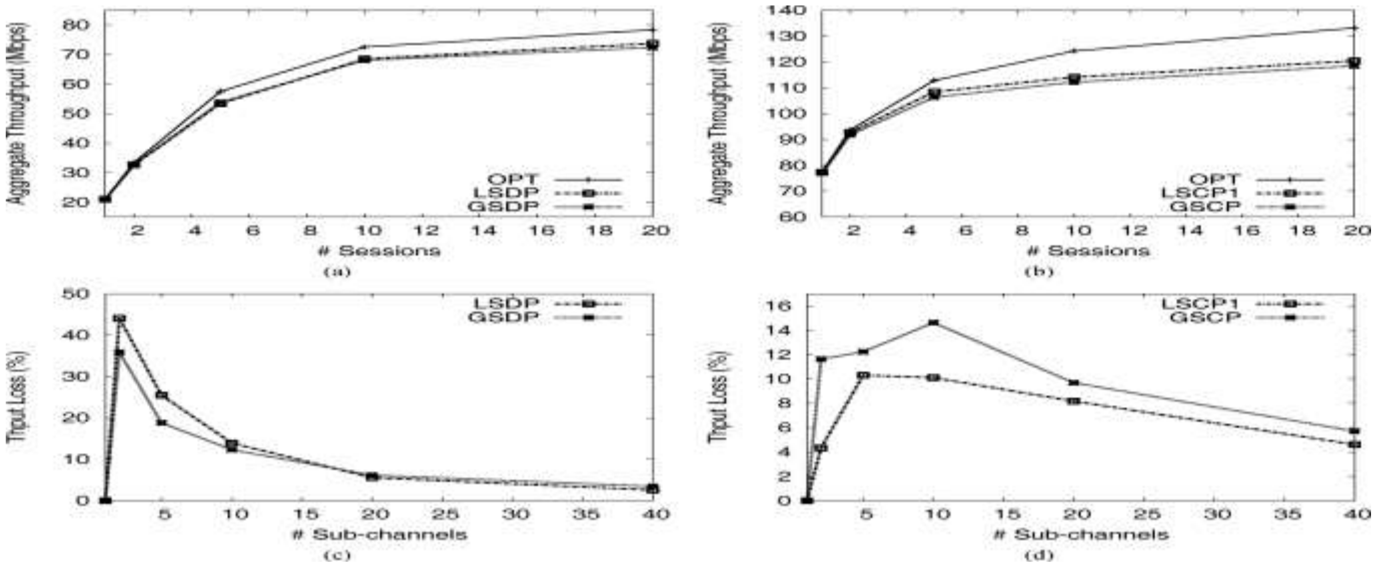


Fig. 4. Performance of multicast scheduling algorithms (a) Impact of sessions (DP). (b) Impact of sessions (CP). (c) Impact of channels (DP). (d) Impact of channels (CP).

A standard deviation of 3.4 and 8 dB for log-normal shadowing is applied for the BS-RS and BS/RS-MS links, respectively.

CONCLUSION

We considered the problem of multicast scheduling in two-hop OFDMA relay networks. We showed that intelligent grouping of relays for cooperation is needed to address the trade-off between cooperation and session multiplexing gains. We designed efficient scheduling algorithms (with performance guarantees) at the core of the multicast strategy to address the trade-off and maximize aggregate multicast flow. Design of network coding mechanisms for multicast retransmissions and its joint incorporation with OFDMA scheduling deserves independent attention and forms an interesting avenue for further research.

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