Rate-Splitting for Multi-group Multicast Beamforming in Multicarrier Systems

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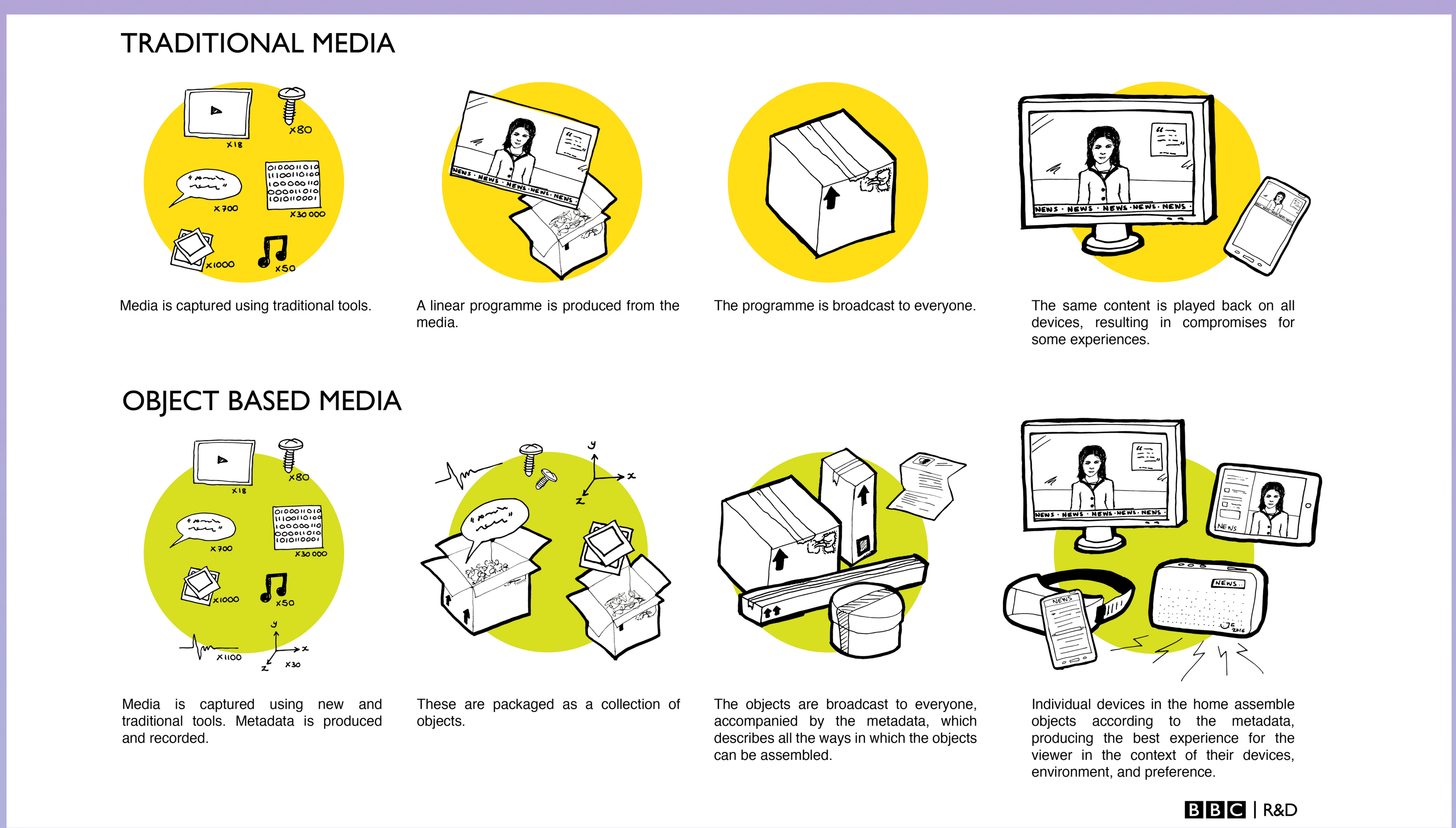
Abstract

In this work, we consider multi-group multicast transmissions with different types of service messages in an overloaded multicarrier system, where the number of transmitter antennas is insufficient to mitigate all inter-group interference. We show that employing a rate-splitting based multiuser beamforming approach enables a simultaneous delivery of the multiple service messages over the same time-frequency resources in a non-orthogonal fashion. Such an approach, taking into account transmission power constraints which are inevitable in practice, outperforms classic beamforming methods as well as current standardized multicast technologies, in terms of both spectrum efficiency and the flexibility of radio resource allocation.

Motivations

Multicast has been identified as an essential candidate in the development of 5G wireless communications towards vertical use cases, e.g., multicast public warning alert and object-based broadcasting (OBB). In particular, OBB enables a more interactive media experience for subscribed users, by turning traditional multicast programs into different types of service messages, named as elements, which allows the users to reassemble programs based on local factors, for example, the device or environment, e.g., background contents and personalized objects including metadata, which allows the users to reassemble programs based on local factors, for example, the device or environment.



It is of great interest to design an efficient multiuser beamforming that simultaneously delivers the different types of service messages by using same time-frequency resources, for the multi-group multicast scenarios where the system relies on the multicarrier transmission like OFDM and is highly likely overloaded. We consider a rate-splitting (RS) multi-group multicast beamforming approach in an overloaded multicarrier system to support the OBB use cases.

Methodology

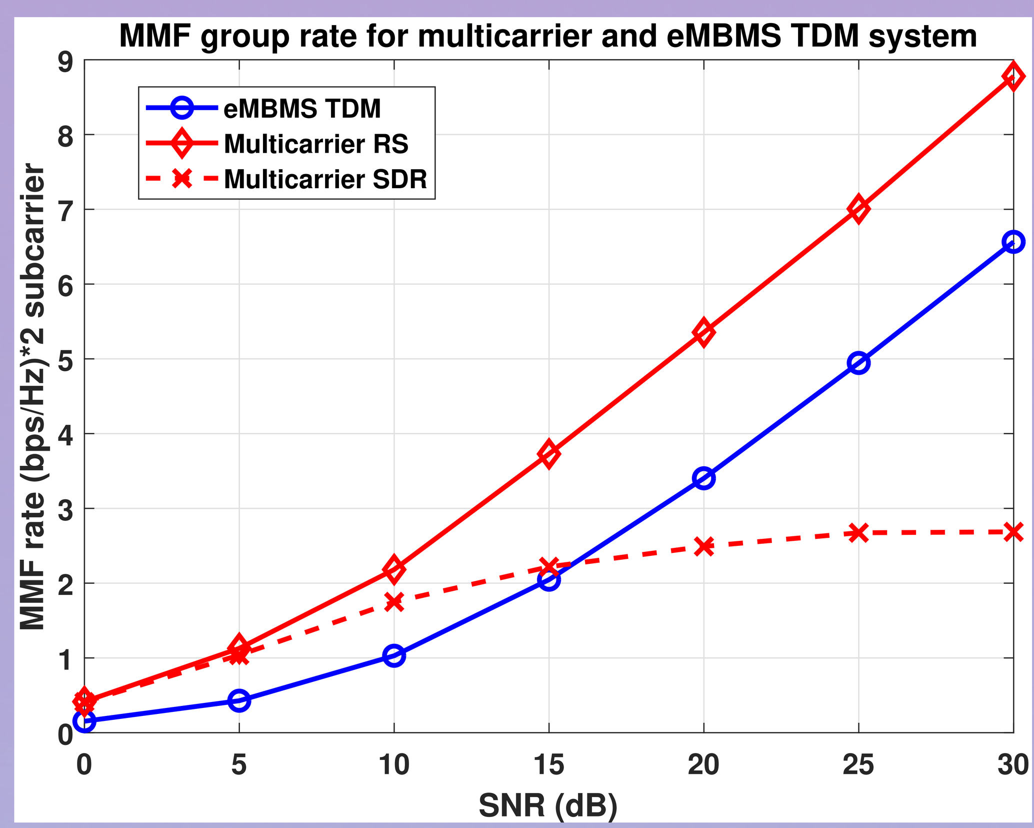
On each subcarrier, each group message is split into broadcast and multicast parts before precoding. Then all broadcast parts form one super message to broadcast, namely broadcast message, which is received and decoded by all users. The rate of broadcast message, to guarantee the successful decoding of which, should equal to the minimum achievable rate among all users, which can be effectively solved by using the weighted minimum mean square error (WMMSE) method which exploits the Rate-MMSE relationship.

$$\mathrm{R}_{sMr}^{RS}(P):\begin{cases}\max\limits_{r_{tot},\mathbf{C},\mathbf{P}_{RS},\mathbf{g},\mathbf{r},\mathbf{v}} & r_{tot}\\ s.t. & \sum\limits_{n=1}^{N}\min\limits_{m\in M} R_{m,n}\geq r_{tot}\\ & C_{m,n}\geq 0,\forall m\in M,\forall n\in N\\ & C_{m,n}+r_{m,n}\geq R_{m,n}\\ & G-\mathrm{W}_{\mathrm{MSE}_{bc,k,n}}\geq\sum\limits_{m=1}^{M}C_{m,n}\\ & G-\mathrm{W}_{\mathrm{MSE}_{k,n}}\geq r_{m,n}\\ & \sum\limits_{n=1}^{N}(\|\mathbf{p}_{bc,n}\|^2+\sum\limits_{m=1}^{M}\|\mathbf{p}_{m,n}\|^2)\leq P\end{cases}$$

* R_{sMr}^{RS}: RS-based sum Max-Min Fair (MMF) rate; K users; M multicast groups; N available subcarriers
$\mathbf{C}\triangleq(C_{1,1},...,C_{m,n},...,C_{M,N})$; $\mathbf{P}_{RS}\triangleq(\mathbf{p}_{bc,1},...,\mathbf{p}_{m,n},...,\mathbf{p}_{bc,N},,...,\mathbf{p}_{M,N})$; $\mathbf{r}\triangleq(r_{1,1},...,r_{m,n},...,r_{M,N})$
$\mathbf{v}$ and $\mathbf{g}$ are weight variables for the weighted MSE: $\mathrm{W}_{\mathrm{MSE}_{bc,k,n}}$ (broadcast) and $\mathrm{W}_{\mathrm{MSE}_{k,n}}$ (multicast)

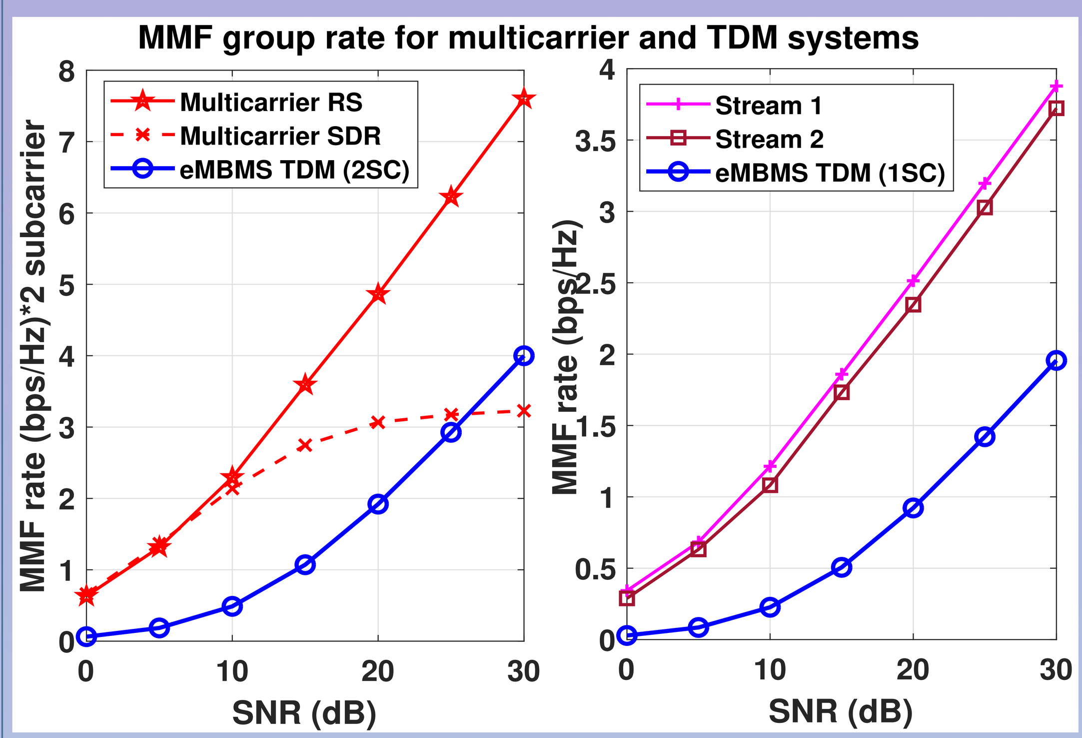
Numerical Results

The performance of the RS-based multicarrier beamforming strategies and the current eMBMS (evolved Multimedia Broadcast Multicast Service) system with Time Division Multiplexing (TDM), is fairly compared in this section, with the identical total power constraint. In a 2-2-2-2 multicarrier system i.e. Available Subcarriers-Transmit Antennas-Multicast group-Users per group and every two users required the same multicast message.



1. Classic Semi-definite Relaxation (SDR) based beamforming (shown as Multicarrier SDR), outperforms the current TDM system at low SNR region (0 to 15dB).
2. Due to performance saturation caused by inter-group interference, TDM system provides better sum MMF-rate at higher SNR region.
3. With RS, the saturation is avoided and the gains of RS over the classic beamforming as well as TDM are very pronounced.
4. RS-based approach significantly outperforms other two methods.

In a 2-4-3-3 system, 3 users per group:



1. This model sets 2 multicast groups as degraded groups.
2. Multi-group multicast integrates more group message into one subcarrier drives the MMF rate difference between RS and TDM even larger (from around 2.2bps/Hz to 3.5bps/Hz @30dB SNR).
3. The multicarrier rate is equivalent to the summation of single carrier rates for each service stream
4. RS-based approach not only provides the non-saturated higher MMF rate than TDM, but also achieves the fairness between all the subcarriers in terms of the MMF rate.

Conclusion

This work presented an optimization problem of a RS-based transmitter beamforming in typical multicarrier multi-group multicasting scenarios. We illustrated that the RS-based approach not only provides higher MMF rate/spectrum efficiency compared to the current TDM-based multicasting within the same time and frequency resource, but also exhibits strictly higher and non-saturated MMF-rates compared to the classic SDR-based beamforming method. We also showed the potential of applying RS in a multicarrier scenario which is close to the systems in practice, e.g., eMBMS in LTE. The considered system can be further developed to be closer to the practical scenario by assuming the imperfect channel estimation, also introducing the RS into the typical transceiver chain and generating bit/block error rate curve can also be of interest in the future work.

Reference

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