Buffer-Aided Cooperative Relays in Orbital Angular Momentum Based IoT Networks

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***Abstract*—Orbital Angular Momentum (OAM) is an essential property of electromagnetic transmission. Nowadays, OAM is popular due to its capabilities to improve the electromagnetic spectrum efficiency which increases throughput. However, employing an OAM-based solution is costly as it suffers wave divergence mainly at high OAM orders (modes). This difficulty limits the distance range for successful communication link, particularly in wireless communication which is essential for realizing Internet of Things (IoT) applications. One of the available solutions to deal with this limitation is utilizing a cooperative relaying system. Relays are known for their potential to shorten the link connecting the source to the destination, as well as provide an alternative link to avoid deep fading. Nonetheless, conventional relaying technique (without buffers) are surpassed by adding buffering capabilities to relays, this enhances the system throughput. In this article, we suggest employing buffer-aided relays in OAM-based networks. Simulation trials show that the proposed buffer-aided relay solution assists the OAM-based network in obtaining higher throughput than its counterpart the traditional relays. The gain of using buffer-aided relays grows as the OAM-based networks become more restricted when they are transmitting at higher OAM orders. Furthermore, at higher thresholds, the rate of successful transmission goes down which degrades the system throughput. The results show that the buffer-aided relays outrun conventional relays at any threshold and the difference in performance becomes greater at more restricted higher thresholds. In addition, the buffer-aided relays help the OAM-based networks achieve lower outage probability than that achieved with traditional relays.**

***Keywords*— Orbital Angular Momentum (OAM), Internet of Things (IoT), buffers, relays, 5G**

I. INTRODUCTION

Currently, wireless connection is the most employed form of communication, therefore, massive connectivity makes wireless communications in upcoming applications more challenging. For example, the Internet of Things IoT (5G and beyond technology) requires massive wireless connectivity while maintaining a high-level throughput, these requirements cannot be met with the available infrastructure [1].

An emerging and promising technology for increasing the efficiency of the spectrum is exploiting Orbital Angular Momentum (OAM) orders (also called modes) which are owned by electromagnetic radiated waves. According to Ref. [2], the radiated electromagnetic wave has a certain form that is OAM. Circular antenna arrays are employed to produce the OAM orders. An OAM mode is a phase dependent incident as it is described by its rotating phase front. The electric field vectors of the ordinary beams are of rotating forms which distinct it from OAM.

The azimuthal phase dependence of OAM phase fronts is $exp\ (jl\emptyset)$ in their distribution of spatial phase where l denotes the OAM order with l is an integer, where in the cylindrical coordinates (r, $\emptyset$, z), $\emptyset$ is the angle of azimuth. The beams of OAM possess zero amplitudes (null) at the beam's centers. In addition, the width of the null region of the radiated beams increases proportional to the z distance of the transmitted array, which is termed as the divergence of the beam. This divergence property of the beam makes it of conic shape [3]. Because of differences in phase between OAM modes, the orthogonality between different orders is secured. The throughput of the system can be extremely boosted in orthogonal OAM orders, this is due to OAM capability of communicating over different orders without occupying additional frequency spectrum, in other words, OAM makes it possible to use the spectrum more efficiently which helps in massive connectivity and higher throughput achievement [4].

The ability of cooperative communication to improve the efficiency of the wireless network makes it a popular technique to achieve future communication technologies [5]. The idea behind cooperative communication is to take advantage of the broadcast property of wireless channel to improve the throughput of the system and to extend the coverage of the network; this is done by installing relay nodes between users in the network. Based on that Long-Term Evolution (LTE) Release 10 has recognized the cooperation with relay nodes as an effective part of realizing modern wireless communications [6]. Relaying can be performed in two methods: Amplify and Forward (AF) and Decode and Forward (DF). The arrived signal to the relay node is amplified and then forwarded to users in AF type, this makes the instrumentation of AF simple, yet it undergoes noise amplification [7]. On the contrary, in the DF method, the relay has the ability to decode the received signal, re-encode it and then the relay transmits the retrieved signal to users. The noise amplification problem is solved with DF mode; however, to achieve an acceptable quality of service QoS, the DF method is greedier to higher channel state is in comparison with AF mode [8]. Due to the relays' effectiveness in battling the

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losses in the communication path, joining cooperative relaying with the state of the arts 5G techniques has been heavily studied in the literature. For instance, the authors of [9] were able to enhance millimeter-wave (mm-wave) communication via utilizing cooperative relaying to enlarge mm-wave coverage. Moreover, Alkhawatrah *et al*. [10] combined cooperative relaying with Non-Orthogonal Multiple Access (NOMA), which led to higher throughput. This promising impact of cooperative relaying inspired the authors in to employ it with an OAM-based network [11], which succeeded to alleviate the divergence of OAM beam, hence, higher levels of system throughput are realized. To summarize, the key novelty of this article is to add buffering capabilities to relays in cooperative OAM-based networks to make it an attractive solution for the challenging IoT applications which require ultra-high data-rates and massive connectivity.

The rest of the article is organized as follows: the literature review is covered in Section II. The system model for the proposed buffer-aided cooperative OAM-based networks is in Section III. The performance analysis of the buffer-aided relay is presented in Section IV. Simulation trials of the system in this study along with a comparison with other available systems are discussed in detail in Section V. Finally, the conclusion is presented in Section VI.

II. LITERATURE REVIEW

An attractive enhancement on relays is adding buffers to relays. The outage probability of the relays with buffers is better and the throughput is better as well when compared with traditional relays (without buffers). This is due to the resilience that having buffers brings, so the constraints of consequence transmitting and receiving are released [12, 13]. There are several research articles have considered buffer-aided relays. Ikhlef *et al.* [14] considered the buffer-aided relays and suggested a max-max relay selection scheme which relaxes the condition that the receiving relay should be the transmitting relay, this relaxation led to better performance by exploiting the best channel. Buffer-aided relays are also studied in [15], where the proposed max-link scheme selects the link with the best channel without keeping the order of receiving and transmitting, which raises the diversity gain of the system. As a result, buffer-aided relays outperform conventional relays when cooperative relaying is combined with familiar 5G techniques such as mm-Wave and NOMA [15–17]. Based on the knowledge of the authors, joining buffer-aided relay with OAM transmission has not been covered in the literature.

Applying the results of ordinary transmission to OAM-based transmission is non-trivial as their propagation properties are different and vary at each OAM-order. Accordingly, motivated by this and by the attractive impact of the buffer relays in realizing higher throughput and reducing outage probability in ordinary transmission, this paper considers employing buffer-aided relays in OAM-based networks. The superiority of the proposed buffer-aided OAM based network is validated in this article analytically and via simulation trials.

III. SYSTEM MODEL

The system model of the proposed buffer-aided cooperative OAM-based network is shown in Fig. 1. Fig. 1 illustrates a source node, a half-duplex DF buffer-aided relay node and a user.

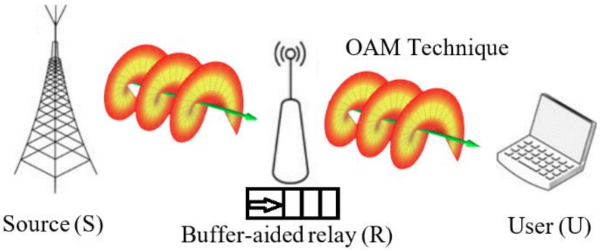

Fig. 1. Buffer-aided cooperative OAM-based network.

A. Relay Networks

In the proposed system the buffer-aided relays are assumed to be of Decode-and-Forward (DF) with transmission of Half-Duplex (HF) with the notation R, sources and users have the notations S and U, respectively. The relay R has a L-size buffer to store the packets. The channel coefficient of the S-R link is denoted as h_{sr}, and the channel coefficients of S-U and R-U links are denoted as h_{su} and h_{ru}, respectively. The channels are assumed to have flat Rayleigh fading coefficients which holds its value during the entire time-slot and its value changes randomly in different time-slots. For simplicity, P_t is the notation for transmit power at all transmitting nodes (source or relay), and σ^2 is the noise variances for all receiving points. The target rate for data transmission is assumed to be constant at ε. If the capacity of a link is higher than or equal to ε, then that link is up, hence it can handle the communication. Otherwise, the link is down and no transmission can take place and the link is said to be in outage.

All receivers are assumed to have information about the states of all links. At a time-slot t, the h_{sr}, h_{su} and h_{ru} channel capacities are calculated as follows:

$$\begin{aligned} C_{sr} &= log(1+\gamma_{sr}(t)) \\ C_{su} &= log(1+\gamma_{su}(t)) \\ C_{ru} &= log(1+\gamma_{ru}(t)) \end{aligned} \quad (1)$$

where $\gamma_{sr}(t) = \frac{P_t}{\sigma^2}\,|h_{sr}(t)|^2$, $\gamma_{su}(t) = \frac{P_t}{\sigma^2}\,|h_{su}(t)|^2$ and $\gamma_{ru}(t) = \frac{P_t}{\sigma^2}\,|h_{ru}(t)|^2$. The channel gains of $|h_{sr}(t)|^2$, $|h_{su}(t)|^2$ and $|h_{ru}(t)|^2$ are distributed according to the exponential distribution with the average $\theta_{sr} = E[|h_{sr}(t)|^2]$, $\theta_{su} = E[|h_{su}(t)|^2]$and $\theta_{ru} = E[|h_{ru}(t)|^2]$, where E[.] stands for the expectation. $\gamma_{sr}(t)$, $\gamma_{su}(t)$ and $\gamma_{ru}(t)$ are also following the exponential distribution with average $\overline{\gamma_{sr}} = \frac{P_t}{\sigma^2}\,\theta_{sr}$, $\overline{\gamma_{su}} = \frac{P_t}{\sigma^2}\,\theta_{su}$ and $\overline{\gamma_{ru}} = \frac{P_t}{\sigma^2}\,\theta_{ru}$. Thus, γ_{sr}, γ_{su} and γ_{ru} are the instantaneous Signal to Noise Ratio (SNR) values, while $\overline{\gamma_{sr}}$, $\overline{\gamma_{su}}$ and $\overline{\gamma_{ru}}$ are the average SNR values for channels h_{sr}, h_{su} and h_{ru} respectively. As mentioned above, if the capacity of the link is lower than the target data rate outage occurs, the outage is calculated based on the fact that $\gamma_{sr}(t)$, $\gamma_{su}(t)$ and $\gamma_{ru}(t)$ are following the exponential distribution, there CDFs are:

$$
\begin{aligned}
P(log(1+\gamma_{sr}(t)) < \varepsilon) &= 1 - e^{-\frac{2^{\varepsilon}-1}{\overline{\gamma_{sr}}}} \\
P(log(1+\gamma_{su}(t)) < \varepsilon) &= 1 - e^{-\frac{2^{\varepsilon}-1}{\overline{\gamma_{su}}}} \\
P(log(1+\gamma_{ru}(t)) < \varepsilon) &= 1 - e^{-\frac{2^{\varepsilon}-1}{\overline{\gamma_{ru}}}}
\end{aligned} \quad (2)
$$

B. *OAM Wave Breakdown*

The OAM wave of mode l has a complex amplitude of the Bessel–Gauss form as follows:

$$u(r, \emptyset) = exp\,(-r^2/d^2) J_l(k_r r) exp\,(jl\emptyset) \quad (3)$$

The exponential term ($exp\,(-r^2/d^2)$) is the wrapping curve of the Gaussian term, d is the wrapping curve width. J_l is the l^{th} order Bessel function of the first kind, r is the coordination of the radial, $\emptyset$ is the azimuth and k_r is the radial frequency [18].

The way OAM wave spreading in space is formed by the paraxial Helmholtz equation:

$$j\frac{\partial u}{\partial z} + \frac{1}{2k_o}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) = 0 \quad (4)$$

where z denotes the propagation distance, $k_o = 2\pi/\lambda$ represents the wave number in vacuum and λ denotes the wavelength. Several popular mathematical tools such as Fourier transform can be used to solve Helmholtz wave equation [19]. This leads to the following familiar form of the Bessel–Gauss wave in non-constrained spreading is as follows:

$$u(r, \emptyset, z) = G\left(\frac{r}{z}, \frac{z}{L}, k_r d\right) J_l\left(\frac{k_r r}{1 + j\frac{z}{L}}\right) e^{jl\emptyset} \quad (5)$$

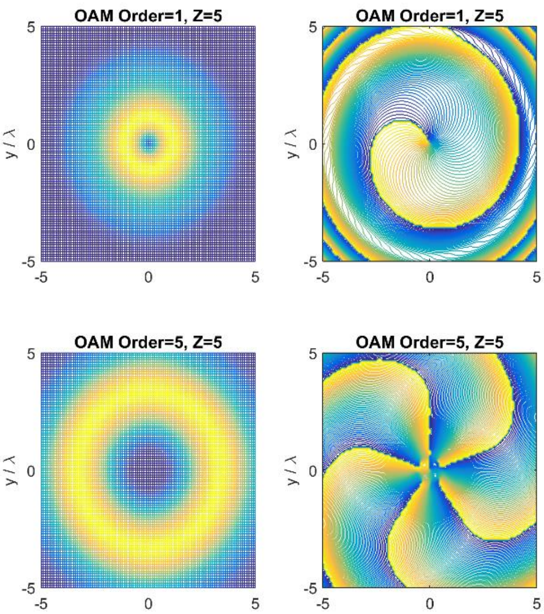

Fig. 2. The distribution of the field spatial amplitude of OAM order = 1 is shown in the upper image (left), and the phase fronts in the upper image (right). Equivalently, the bottom images are for the OAM order = 5.

where $L = \pi d^2/\lambda$ represents the Rayleigh distributed distance of the Gaussian wrapping curve, and the expression G is the Gaussian wrapping curve propagation which is independent of the OAM mode l [20]. Fig. 2 shows the distributions of the transversal spatial of Bessel–Gaussian waves at different OAM orders. We normalized all distances in the figure to the value of λ. In the figure, the move in the color appearance from blue to yellow indicates an increment in the field intensity. The intense blue color at the center of the represents the amplitude null. At higher OAM orders, the amplitude null becomes wider. The right part of Fig. 2 shows the phase fronts in the plane which meets the beam at z=5 away from the transmitter circular antenna array. The rotational property of the phase front of the OAM beams is illustrated in Fig. 2 for two cases OAM mode 1 and OAM mode 5. The OAM mode is identical to the rotational phase fronts number.

C. *Problem Formulation*

Opposed to ordinary transmission, the OAM transmission has a higher capability to achieve higher throughput via exploiting spectrum more effectively. However, the excellence of OAM is limited by the divergence and the state of the transmission link. Therefore, conventional relays were employed to shorten the distance between the source and the user, hence, the divergence and the deep fading problems are mitigated to some extent. On the other hand, buffer-aided relays outperform conventional relays in dealing with these problems due to their flexibility in exploiting good channel realizations perfectly. In other words, conventional relays require consecutive good channels, otherwise, the data is lost, while buffer-aided relays release this constraint and keep the packets until the next good channel state. In this paper, applying buffer-aided relays under OAM transmission, rather than conventional relays, is expected to improve the overall system throughput by keeping the successfully received packets from the source until they can be re-transmitted to the user.

D. *Performance Analysis*

A Buffer-aided relays are adequate to lessen the probability of an outage, therefore, the system throughput is increased. This is why the buffer-aided relay is an interesting technique to improve the operation of conventional OAM-based cooperative networks. This section verifies mathematically the excellence of the buffer-aided relay set side by side with conventional non-buffer relay. In each buffer-aided relay, the state of the relay represents the number of data packets stored in its buffer. Considering that the number of relays is M with buffer-size equal to L, hence, the number of states is $(L+1)^M$ states. Every state influences the availability of S → Rm and Rm → U links. The S → Rm link is available if the receiving buffer is capable to receive the packet (not full), while any Rm → U link is available when the transmitting buffer has packets for transmission (not empty). It is worth mentioning that the direct S → U link is omitted from the comparison as it is common in both systems the buffer-aided and the conventional relay systems. The vector of the n-th state is as follows:

$$\boldsymbol{s}^n = \left[{s_1}^{(n)}, {s_2}^{(n)}, \dots, {s_M}^{(n)}\right], n = 1, \dots, (L+1)^M \quad (6)$$

where ${s_m}^{(n)}$ is the content of the buffer when the system is at s^n at relay R_m.

By considering the entire states, the probability of the system being in outage is calculated as the ratio of the system is not moving from the current state, this implies no connection has happened (receiving or transmitting). Based on that to obtain the probability at which the is being in outage we follow:

$$P_{out} = \sum_{i=1}^{(L+1)^M} {P_{out}}^{s^{(i)}} \pi_i \quad (7)$$

where π_i denotes the stationary probability for the state $s^{(i)}$, and ${P_{out}}^{s^{(i)}}$ is the outage probability at the state $s^{(i)}$. We assume that all links are independent and identically distributed, the outage occurs if all transmitting links and all receiving links are in outage:

$$P_{out} = \left(1 - e^{-\frac{2^{\mathcal{E}}-1}{\overline{\gamma_{SR_m}}}}\right)^{{O_{s^{(n)}}}^{SR_m}} \left(1 - e^{-\frac{2^{\mathcal{E}}-1}{\overline{\gamma_{SR_mU}}}}\right)^{{O_{s^{(n)}}}^{R_mU}} \quad (8)$$

where ${O_{s^{(n)}}}^{SR_m}$ is the notation for the count of available S → R_m links at state $s^{(n)}$, and ${O_{s^{(n)}}}^{R_mU}$ is the count of available R_m → U links at state $s^{(n)}$.

In buffer-aided relays, Markov chain in its discrete time form can be utilized to model the buffer states. The matrix **A** is the transition matrix of the buffer states with $(L+1)^M$ × $(L+1)^M$ state transition. **A**ij is the notation for the i^{th} row and j^{th} column element, which represents the change probability to go from state $s^{(j)}$, at time t to state $s^{(i)}$, at time t + 1:

$$\mathbf{A}\text{ij} = P(X_{t+1} = s^{(i)} | X_t = s^{(j)}) \quad (9)$$

Since exploiting the OAM modes changes the number of packets that can be transmitted at a time slot, this affects the entries of **A** and makes it non-trivial (not sparse) to be calculated. Before giving an example of calculating **A**, as mentioned in [11] the received power threshold is what decides the OAM mode. Let us denote the level of the received power which satisfies a specific OAM mode as α_i, the subscript i represents the OAM order and α_i equals 1 only at OAM order i and 0 for the higher OAM orders. For instance, if α1 = 1, this means that the received power is enough to support OAM mode 1 and the higher OAM modes such as α_2 are all zeros. Now we can see an example on calculating A, to not complicate the calculations let L = 3 and the number of modes is up to 3 modes, the transition matrix of the Markov chain is:

$$\mathbf{A} = \begin{bmatrix} \overline{(S-R)} & (R-U)\alpha_1 & (R-U)\alpha_2 & (R-U)\alpha_3 \\ (S-R)\alpha_1 & \overline{(S-R)}\,\overline{(R-U)} & (R-U)\alpha_1 & (R-U)\alpha_2 \\ (S-R)\alpha_2 & \overline{(R-U)}\,(S-R)\alpha_1 & \overline{(S-R)}\,\overline{(R-U)} & (R-U)\alpha_1 \\ (S-R)\alpha_3 & \overline{(R-U)}\,(S-R)\alpha_2 & \overline{(R-U)}\,(S-R)\alpha_1 & \overline{(R-U)} \end{bmatrix}$$

where $\overline{(.)}$ indicates that the specified link between the parentheses is in outage and (.) means the link is not in outage. The above Markov chain is irreducible as each state can be reached from any state, the chain is also aperiodic as it is possible to stay at any state, see [21, 22]. As shown in [10], for irreducible and aperiodic Markov chain, the probability vector for the stationary state is calculated as follows:

$$\boldsymbol{\pi} = (\mathbf{A} - \mathbf{I} + \mathbf{B})^{-1}\mathbf{b} \quad (10)$$

where $\boldsymbol{\pi} = [\pi_1, \pi_2, \cdots, \pi_{(L+1)}]$, π_i is the probability that state is s_i, the vector $\mathbf{b} = [1, \cdots, 1]^T$, **I** is the popular identity matrix and the one matrix **B** is an (L + 1) × (L + 1) of its elements all ones. Hence, the probability that the buffer-aided relay system is in outage can be easily calculated by measuring the ratio that the system Markov chain pause in the current state:

$$P_{out} = \sum_{i=1}^{(L+1)^M} \pi_i \mathbf{A}_{ii} \quad (11)$$

where $\mathbf{A}_{ii}$ can be found in the main diagonal of the matrix **A**. Distinct from the case with the non-buffer relay where both S → R and R → U links have to be able to support transmission simultaneously to success in communication, in the buffer-aided relay, any available S → R or R → U is enough to handle the transmission. This doubles the diversity gain of the relay with buffer compared with the non-buffer relay (in [23]). Accordingly, the probability of outage degrades buffering capability is provided to the employed relays:

$$1 - \left(e^{-\frac{2^{\mathcal{E}}-1}{\overline{\gamma_{sr}}}} \times e^{-\frac{2^{\mathcal{E}}-1}{\overline{\gamma_{ru}}}}\right) \geq 1 - \left(e^{-\frac{2^{\mathcal{E}}-1}{\overline{\gamma_{sr}}}} + e^{-\frac{2^{\mathcal{E}}-1}{\overline{\gamma_{ru}}}}\right) \quad (12)$$

exploiting the fact that $0 \leqslant e^{-\frac{2^{\mathcal{E}}-1}{\overline{\gamma}}} \leqslant 1$ (probability). For transmission that is limited by delay as in [24, 25], the average throughput is obtained as:

$$\bar{\xi} = \epsilon(1 - P_{out}) \quad (13)$$

The superiority of the buffer-aided relay is obvious to their counterpart the non-buffer relays in terms of the system throughput because of outage probability reduction.

IV. Simulation Results

This section presents the outcomes of the simulations to confirm the above analysis. We examine the efficiency of the suggested buffer-aided relay cooperative OAM-based scheme. In the simulations, we assume that the variance of the noise σ^2 is normalized to unity and we follow [26] in assuming that data rate ε = 2 bps/Hz. The buffer-size is L = 50. Firstly, we show the effect of the size of the receiving aperture on the received power. The buffer does not change the effect of the size on the received power; therefore, the results are similar to these in [11].

A receiver is built by an adequate number of sensors around a circular element. In the several sizes shown in Fig. 3, the size of the receiving aperture matches the maximum intensity radius of a specific OAM order. As shown in the left column of Fig. 2, the maximum intensity of a certain OAM order appears as a ring with a certain radius. The impact of using the right size for each OAM order is illustrated in Fig. 3. For example, size 5 means that the receiver aperture size matches the maximum intensity radius for OAM order 5, hence, the highest level of the received power at order 5 is harvested at size 5 or larger sizes, this is true for all orders. As shown in Fig. 3, the normalized received power declines at higher OAM order increases. However, with an aperture of larger size, a sufficient amount of received power is maintained at high OAM orders. Fig. 3 shows the levels of the normalized received power, we can use these levels as thresholds for successful receiving. So, setting the threshold at 90 percent means that the normalized received power is 0.9 in Fig. 3.

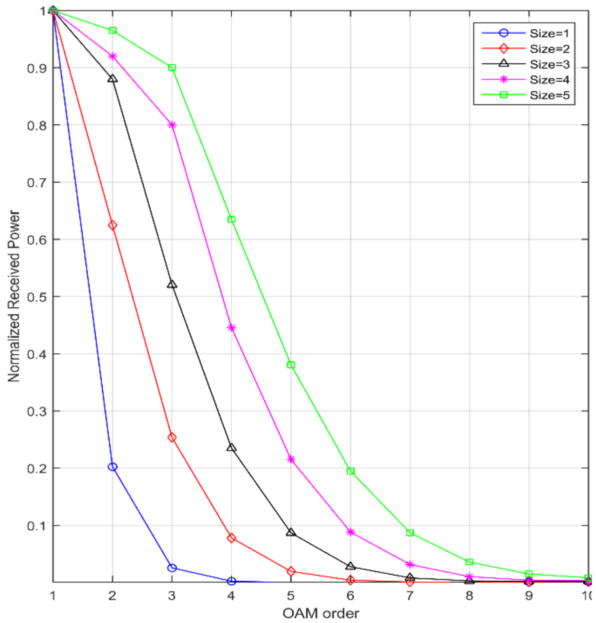

Fig. 3. The impact of the receiver aperture size on the normalized received power of the system at several OAM orders [11].

Fig. 4 shows the results of comparing the throughput at different OAM modes between two systems: the traditional cooperative relay in an OAM-based solution [11] and the proposed buffer-aided relay cooperative OAM-based scheme. The horizontal access shows different values of P_t and increasing the SNR satisfies the receiving threshold, and enhances the throughput. The receiving threshold is set to 70 percent in this figure. It is obvious that the proposed scheme outperforms the traditional scheme in all cases. It is interesting to notice that as the transmission gets more restricted the flexibility that buffers provide becomes more beneficial. For example, at OAM mode 1, the achieved throughput of the buffer-aided relay at 20 dB SNR is about 0.5 packets per time slot above the one for the traditional relay. As the OAM modes are increased the transmission gets harder due to an increment in the divergence of the signal, this is the case when moving from OAM mode 1 to mode 3 and mode 5. At mode 3, the difference between the achieved throughput of the two systems is as follows: buffer-aided relay at 20 dB SNR is about 1 packet per time slot higher than that for the traditional relay, and the difference is even bigger in mode 5 where the buffer-aided relay at 20 dB SNR outperforms the traditional relay in about 1.5 packets per time slot of throughput. This supports the fact that in more restricted transmission, the ability to re-transmission that buffers provide is more valuable.

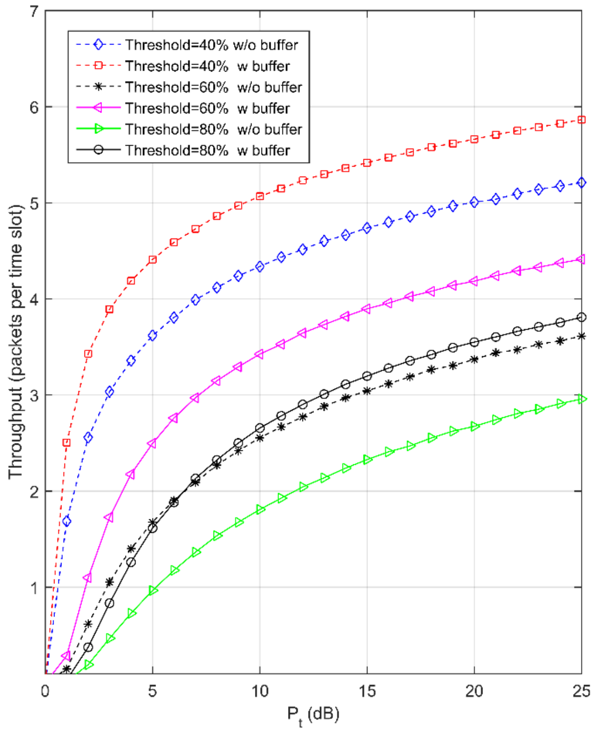

Fig. 4. Throughput comparison of different OAM modes between two systems: the traditional cooperative relay in OAM-based solution and the proposed buffer-aided relay cooperative OAM-based scheme.

Fig. 5 shows the results of comparing the throughput at different received power thresholds between the two systems: the traditional cooperative relay in OAM-based solution [11] and the proposed buffer-aided relay cooperative OAM-based scheme. The selected OAM order in this figure is 3. It is noticeable that reducing the threshold relaxes the restrictions of the reception so higher OAM orders at lower thresholds are attainable; therefore, an increment in throughput is achieved at low thresholds. This is validated by the results shown in Fig. 5. In particular, the most restricted case is the 80 percent threshold, the lowest values of the throughput are at this threshold between the three thresholds. It is obvious that the proposed scheme outperforms the traditional scheme in all cases. The same interesting result in Fig. 4 appears in Fig. 5 as well. Specifically, as the transmission gets harder the flexibility that buffers provide becomes more useful. For instance, by comparing the throughput enhancements of the buffer-aided relay above the traditional relay at 40 percent and 80 percent thresholds, the throughput performance difference between the buffer-aided relay and the traditional relay is more obvious at 80 percent threshold. It is worth noting that the buffer-aided relay can work under a high threshold better than the traditional relay at a lower threshold. For example, the throughput of buffer-aided relay at 25 dB with 80 percent threshold is higher than that for the traditional relay at 25 dB with 60 percent threshold.

Finally, in Fig. 6, the outage probability of the two systems is compared. The buffer-aided relay has a lower outage probability than the traditional relay. This enhancement is due to the buffer ability to relax the demand for two consecutive successful transmission from S → R and R → U. The buffer keeps the packet after receiving it from the source S and once the R → U channel is up, the packet is directly transmitted to the user.

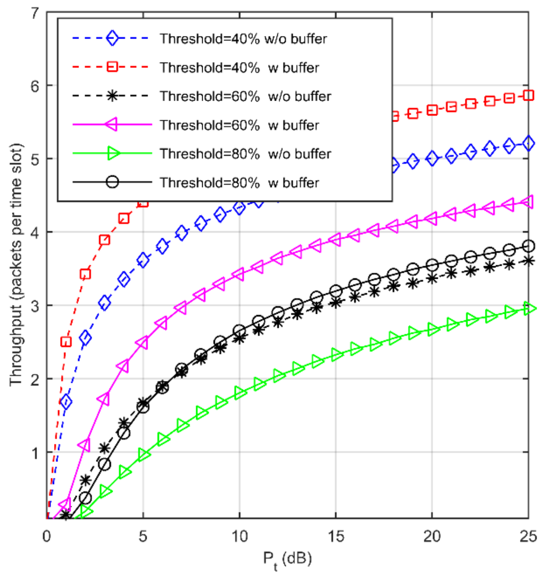

Fig. 5. Throughput comparison at different received power thresholds between the two systems: the traditional cooperative relay in OAM-based solution and the proposed buffer-aided relay cooperative OAM-based scheme.

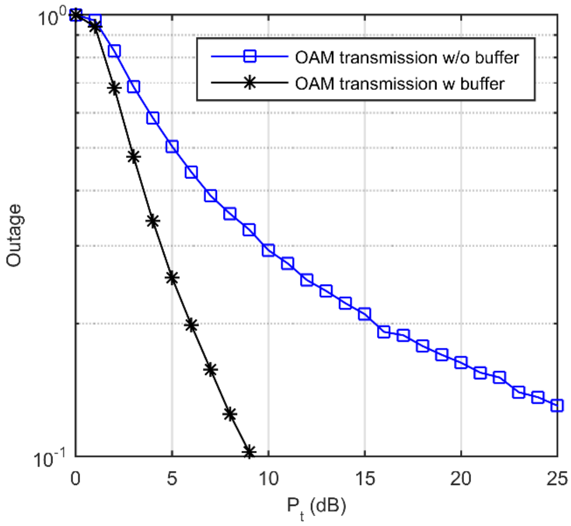

Fig. 6. The outage probability comparison of the traditional cooperative relay in OAM-based solution and the proposed buffer-aided relay cooperative OAM-based scheme.

V. Conclusion

This article suggests employing buffer-aided relays in OAM-based networks. This is urged on the capabilities of the buffer-aided relay to keep the packets till it has a sufficient channel for communication, while the conventional relay discards the packets that fail to transmit instantly, which results in a re-transmission burden. The suggested buffer-aided relay technique assists the OAM-based network in realizing higher throughput than its counterpart the conventional relays. The gains of using buffer-aided relays increase as the OAM-based networks become more restricted when they are transmitting at higher OAM orders. The received power threshold has a notable impact on the system throughput. As the threshold increases, the rate of successful transmission goes down which degrades the system throughput. It turns out that the buffer-aided relays outperform traditional relays at all thresholds and the difference in performance becomes greater at more restricted higher thresholds. Lastly, the buffer-aided relays help the OAM-based networks in achieving lower outage probability than that achieved with traditional relays.

Conflict of Interest

The author declares no conflict of interest.

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