Repairable Fountain Codes with Unequal Locality for Heterogeneous D2D Data Storage Networks

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Abstract. In this paper, we consider a problem about a novel distributed erasure code, named repairable fountain code (RFC), used in heterogeneous networks (HetNets) including different micro base station (MBS) coverage areas, for data storage and delivery among the devices connected by D2D links. The system model of three-tier MBS distributed data storage network is presented and the basic principle is also detailed illustrated. Then, the downloading and repairing communication costs of RFC are analyzed based on its rateless, systematic and lower locality properties. Particularly, the unequal repair locality of RFC (URL-RFC) is designed and discussed for the adaption to the different mobilities with the Poisson process of the nodes in three MBS coverages, and to further reduce the energy cost. The simulation results show that, the URL-RFC scheme we proposed can obtain the lowest cost performance in the case of instantaneous repair, and the cost of URL-RFC is larger than that of RFC when the repair interval is also larger, but it will finally approach to the RFC communication cost curve.

Keywords: HetNets · D2D link · Data storage · Repairable fountain codes · Locality · Communication cost

1 Introduction

It is predicted that the amount of mobile data will reach 49 exabytes per month in 2021, compared to 32 exabytes per month in 2018. The rapid growth of mobile data has brought tremendous pressure on the storage systems and cellular communication networks. While heterogeneity is a significant feature as we known in the next wireless communication networks (5G) with huge data traffic. Considering the limited connections within small cells and the imbalanced capabilities

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among different coverages, we can see that for a heterogeneous network (HetNet) consisting of multi-tier base station (BS) or micro base station (MBS) [1]. While the device-to-device (D2D) communication technique [2,3] is to be widely spread used for lower energy transmission among various classes of low-power nodes (e.g. mobile phone, notebook and tablet). Recently, distributed storage system (DSS) can be established by D2D links in a coverage of BS, to save the power expenditure for large and popular content downloading and sharing continually among different users [4]. Because D2D nodes can replace the MBS and BS for data storage and distribution, this issue is widely studied in some low-energy communication scenes [5].

One serious problem in this topic is the mobility of the users in wireless HetNets, which will make the data stored in various nodes lost, and reduce the availability of DSS composed by unstable D2D links. So the lost data has to be repaired and reconstructed in new coming nodes. Then many literatures focus on some classical redundant error corrections (e.g. replication, MDS codes, regenerating codes [6,7]) used in one BS coverage for wireless content delivery. The instantaneous repair and interval repair are both employed for bring down the downloading and repairing costs [8]. But the essential conditions about sufficient number of helper nodes and bigger storage occupation make the performance gain not outstanding. On the other hand, the influence mechanisms and relationships of the heterogeneity (i.e. power, distances, number of nodes) of the MBSs and devices is difficult to discuss over HetNets. Therefore, some new coding schemes should be attempted to enhance the feasibility and efficiency in D2D HetNets for data restore and delivery.

The Repairable fountain code (RFC) is a new family of fountain codes that can be applied to DSS. RFC has the rateless property, and each encoded symbol is generated independently, so that the encoded symbol can be dynamically added or deleted without recreating the entire encoded process. Because the input symbols are reproduced as systematic symbols in encoding, when there is a requirement to download one data block of the source file, the data block can be directly acquired without decoding. In addition, D2D HetNet systems require frequently data repair under different MBS energy supplies, the RFC can be repaired at a lower bandwidth than MDS code due to its lower repair locality of $O(logk)$ [9]. Therefore, for D2D HetNets, the RFC has some application potential for unequal data reconstruction. Previously, the studies on the unequal error protection of Fountain codes in broadcast transmission have been extensive [10,11], and the local repairable codes have also been initially studied in terms of unequal failure protection [12].

The contributions of this paper includes two aspects: Firstly, we propose a novel unequal repair locality based on RFC, termed URL-RFC, which trades off heterogeneity of MBS and devices in D2D storage networks. The URL-RFC uses different RFC coding schemes over different MBS coverage areas, and provides different repair localities by allocating unequal input symbols and encoded symbols, thereby reducing the overall communication costs of the system. Secondly, the system model of 3-tier MBS distributed network is presented and the communication costs analysis and formula derivation of 3-tier HetNet system are carried out, and the communication cost of URL-RFC scheme compared with other coding schemes is also analysed.

The structure of this paper: Sect. 2 gives the system model of 3-tier heterogeneous D2D distributed storage system. Section 3 introduces the construction of the RFC. In Sect. 4, we analyze and compare the communication costs of the replication scheme, RFC scheme, and URL-RFC storage scheme. The simulation results are given in Sect. 5, which prove that the URL-RFC scheme can reduce the costs of heterogeneous D2D systems in some cases. Section 6 summarizes the main research contents of this paper.

2 System Model

We consider a 3-tier heterogeneous D2D distributed storage system, as shown in Fig. 1. This system consists of a macro base station (BS) that covers the entire system area. In order to reduce the power consumption of the base station, the whole coverage area is divided into M identical sub-areas $Area1, Area2, \cdots, AreaM$, and M micro base stations(MBS) $MBS1, MBS2, \cdots, MBSM$ are used. Two adjacent sub-areas can be covered by one MBS to form a layered network structure. The N mobile devices (nodes) in each area can enter and exit the system randomly, subject to the Poisson process. The entry and exit rates of nodes in different areas can be different, and we assume that the departure rate of each node in area m is μ_m, and the rate at which new nodes enter the system is $N\lambda_m$. Mobile devices in the same area can communicate using D2D links to further reduce communication costs.

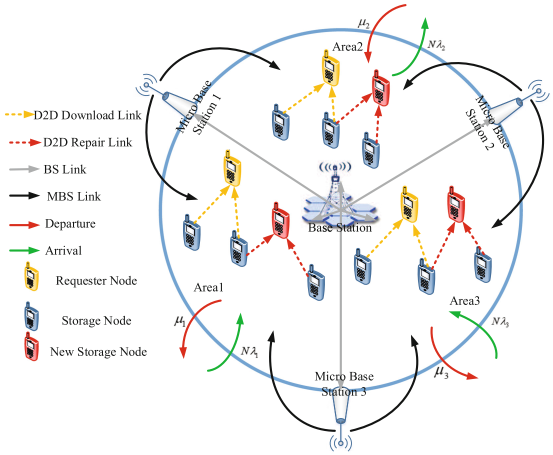


Fig. 1. Three-tier heterogeneous D2D distributed storage system model.

It is noted that only one file exists in the network system and is stored in the MBS and the mobile device, so that all user devices covered by the BS can quickly use the D2D link to cooperate with the MBS for file downloading. If the number of D2D links is insufficient, MBS and BS will be used. At the same time, in order to ensure the availability of the entire network system, it is necessary to perform data repair on the leaving node/new incoming node, which includes D2D link repair and MBS/BS link repair.

The research in this paper is based on the following basic assumptions:

1. Mobile devices in the same area can transmit data through an error-free and delay-free D2D link, which ensures that a theoretically sufficient number of D2D link connections can instantaneously complete file download and data repair.
2. The ρ_{D2Dm}, ρ_{MBS}, and ρ_{BS} represent the energy cost of transmitting 1-bit data between mobile devices in area m, the energy cost of the MBS transmitting 1-bit data, and the energy cost of the BS transmitting 1-bit data, respectively. According to the different pass loss of wireless signals, i.e., lager distance more energy, the average $\rho_{MBS} > \rho_{SBS} > \rho_{D2Dm}$ can be obtained.
3. For simplicity, there is only one file of size F in the BS.
4. Assume $\mu_m = \lambda_m$, that is, the traffic in and out of each area is the same, and the average number of nodes in the area stays constant N. The number of nodes in each area can be described by a $M/M/\infty$ Markov process.
5. The number of encoded symbols n_m for each area satisfies $n_m << N$, hence the probability that the number of nodes in the area is smaller than n_m is negligibly small [13]. Therefore, the file can always be stored in the network.

Data Storage: The file is divided into 3 parts. For any area m, two adjacent MBSs store $fracF3$ files. The remaining $fracF3$ files are stored in the mobile devices(blue mobile phone) called storage nodes through the redundancy strategy of distributed storage. We consider a uniform allocation in our system model. Hence each storage node in area m stores α_m bit data.

Data Repair: When the storage node in the area leaves the area, the data stored in the node will also be lost. In order to ensure that when a user requests to download a file, the file can be obtained by consuming less energy, the lost data needs to be repaired in time and stored on a new node (red mobile phone). If the storage node is repaired immediately when it is lost, it will increase the burden of base station supervision, and this is difficult to implement in practical applications [14]. Therefore, this paper studies a system with a certain repair interval. At the time of repair, if there are enough storage nodes in the area, the data can be repaired through the D2D link, and the repair bandwidth is R, that is, the minimum number of connectable storage nodes required for D2D repair is $\gamma_{D2D} = d\alpha$. Otherwise, it can only be repaired by the BS and the repair bandwidth is $\gamma_{BS} = \alpha$. It should be noted that when $\rho_{D2D}\gamma_{D2D} < \rho_{BS}\gamma_{BS}$, i.e. $d < \frac{\rho_{BS}}{\rho_{D2D}}$, D2D repair is advantageous compared to using BS for repair.

File Download: Assume that the rate of each node requesting a file is ω. When the node in the area requests to download the file, if the number of storage nodes in the area is sufficient, the D2D link can be jointly downloaded with two adjacent MBSs, where the D2D link can provide the data of the $h\alpha$, that is, the number of storage nodes needed to be connected is not less than h, and the two MBSs provide $fracF3$ data, respectively. Otherwise, the download should be jointly performed by the two adjacent MBSs and BS, in which $fracF3$ data is downloaded from each MBS, and the remaining $fracF3$ is downloaded from BS. It should be noted that when $\rho_{D2D}h\alpha < \rho_{BS}\frac{F}{3}$, i.e., $frac3h\alpha F < \frac{\rho_{BS}}{\rho_{D2D}}$, the joint download using D2D and MBSs is superior to the joint download using BS and MBSs.

3 RFC and URL-RFC

3.1 Construction of RFC

Repairable fountain code (RFC) inherits the rateless property of classical fountain codes, so we do not need to pre-determine the number of coded symbols. Unlike classical fountain codes, the RFC is a systematic code and its parity symbols also have logarithmic sparseness [15].

The RFC divides the source file into k packets when encoding, i.e. k input symbols. The input symbols are encoded by the generator matrix of $k \times n$, resulting in n encoded symbols containing a copy of k input symbols and $n - k$ parity symbols. Let the vector v represents the encoded symbol, and the vector u represents the input symbol. The construction method of the RFC can be represented by Fig. 2, each parity symbol is generated by a linear combination of $d(k) = clogk$ input symbols selected uniformly at random. The coefficient ω of the linear combination is selected from the finite field F_q, and c is a constant. Therefore, the generator matrix can be represented as $\mathbf{G} = [\mathbf{I_k}|\mathbf{P}]$, as shown in Fig. 3. The identity part of $\mathbf{G}$ corresponds to the systematic symbols, and the matrix $\mathbf{P}$ corresponds to the parity symbols. Any encoded symbol can be expressed as

$$v_j = u\mathbf{G}(j) = \sum \omega_{ij} u_i, \tag{1}$$

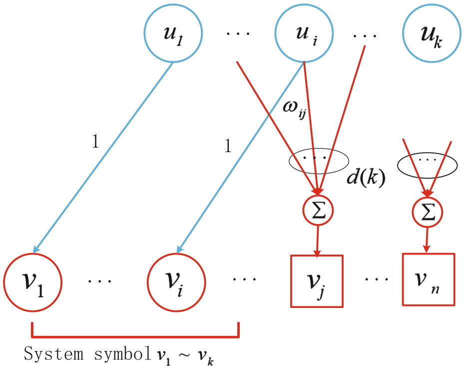


Fig. 2. RFC encoding process.

$$\mathbf{G}[\mathbf{I_k} \mid \mathbf{P}] = \left[\begin{array}{cccc:ccc} 1 & \cdots & \cdots & 0 & \omega_{1,k+1} & \cdots & \omega_{1,n} \\ \vdots & \ddots & & \vdots & \vdots & & \vdots \\ \vdots & & \ddots & \vdots & \vdots & & \vdots \\ 0 & \cdots & \cdots & 1 & \omega_{k,k+1} & \cdots & \omega_{k,n} \end{array}\right]$$

k input symbol columns n-k parity symbol columns

Fig. 3. RFC encoding process.

where $\mathbf{G}(j)$ represents the jth column of the generator matrix $v_j = u\mathbf{G}(j) = \sum \omega_{ij} u_i$.

The encoding process can be expressed as a formula

$$v = u\mathbf{G}[\mathbf{I_k}|\mathbf{P}]. \tag{2}$$

A parity symbol along with the systematic symbols covered by it form a local group. Any symbol in the local group can be reconstructed by the linear combination of other symbols in the local group, and the local group size is $d(k)+1$. The RFC trades its low locality with its MDS property, but it still possesses near-MDS property. When downloading the entire file, a very small decoding overhead $\varepsilon > 0$ is required, so that any subset of $k' = (1+\varepsilon)k$ symbols can reconstruction the file. The maximum likelihood decoding method can be used for decoding, which is equivalent to solving the solutions of k' linear equations.

We refer to the set of a parity symbols along with the systematic symbols covered by it as a local group. When repairing a lost encoded symbol, connecting the other encoded symbols in the local group can reconstruct the lost encoded symbols by Eq. (1). The new generator matrix $\mathbf{G_S}$ is composed of the columns of the symbols in the available helper storage nodes, which is a submatrix of G. When decoding, if $\mathbf{G_S}$ is a full rank matrix, the input symbols can be decoded by $u = v{\mathbf{G_S}}^{-1}$.

It can be seen from the encoding process of the RFC that the local group size is $d(k)+1$. The RFC exchanges its MDS property for lower locality, but still has the property of near-MDS. When downloading the entire file, a small decoding overhead $\varepsilon > 0$ is required, so that any $k' = (1+\varepsilon)k$ encoded symbols can reconstruct the source file.

3.2 Unequal Repairing Locality Based on RFC

We consider that the departure rate and the energy cost of transmitting 1-bit data of mobile devices in different areas are different. In order to further reduce the overall communication cost of the HetNet system, we design a repairable fountain code with unequal parameters in different areas based on the RFC, to adapt to the changes in different areas. Therefore, our coding scheme is called Unequal Repair Locality based on RFC (URL-RFC).

Considering the limited space, the coding process is illustrated just in 2-tier HetNet models. Assume that the number of input symbols in the two regions is k_1 and k_2, respectively, u_1 to u_2 represent the input symbols of $Area1$, and the input symbols of $Arae2$ are from u'_1 to u'_2. The two sets of input symbols are separately encoded and stored in the nodes of $Area1$ and $Area2$, respectively. As shown in Fig. 4, the encoded symbols of the $Area1$ includes the copy of u_1 to u_2 and a set of parity symbols of degree $d(k_1)$ generated by u_1 to u_2, and the number of encoded symbols is n_1. The encoded symbols of the $Area2$ contains the copy of u'_1 to u'_2 and a set of parity symbols of degree $d(k_2)$ generated by u'_1 to u'_2, and the number of encoded symbols is n_2.

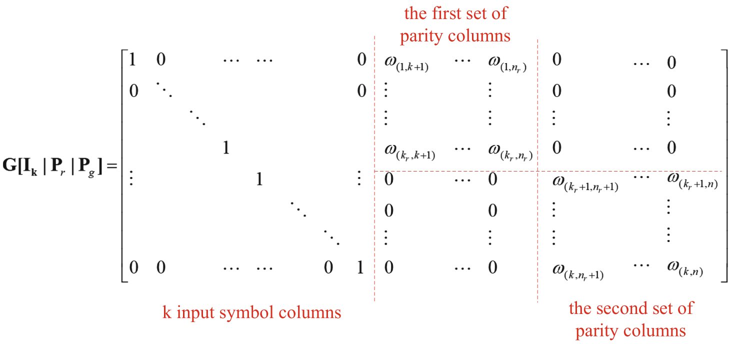


Fig. 4. URL-RFC encoding process.

4 Communication Costs Analysis

In this section we derive the analytical expressions for repair cost $(E(C_r))$, download cost $(E(C_d))$, total communication cost $(E(C))$. The cost is defined in cost units per bit and time unit.

Repair Cost: Within the repair interval Δ, the entire system has i storage nodes leaving, and $0 \leq i \leq Mn$. The probability that any area m leaves i_m storage node obeys the binomial distribution with the parameter (n_m, p_m), and its probability mass function is

$$b_{i_m}(n_m, p_m) = \binom{n_m}{i_m} (1 - p_m)^{i_m} p_m^{n-i_m}, 0 \leq i_m \leq n_m, \tag{3}$$

where, $p_m = e^{-\mu_m \Delta}$, $\sum\limits_{m=1}^{M} i_m = i$.

For any area m, when $0 \leq i_m \leq n_m - d_m$, that is, the number of remaining storage nodes is $l_m \geq d_m$, it can be repaired through the D2D link. Therefore, the probability of repairing through the D2D link is $\sum\limits_{i_m=0}^{n_m-d_m} b_{i_m}(n_m, p_m)$, and the repair cost is $C_{r_m} = i_m \rho_{D2Dm} \gamma_{D2D}$. When $n_m - d_m < i_m \leq n_m$, that is, the number of remaining storage nodes is $l_m < d_m$, it can only be repaired by the BS. The probability of repairing through the BS is $\sum\limits_{i_m=n_m-d_m+1}^{n_m} b_{i_m}(n_m, p_m)$, and the repair cost is $C_{r_m} = i_m \rho_{BS} \gamma_{BS}$. Therefore, the average repair cost of the area m is

$$\begin{array}{c} E(C_{r_m}) = \frac{1}{F\Delta}[\rho_{D2Dm}\gamma_{mD2D} \sum\limits_{i_m=0}^{n_m-d_m} i_m b_{i_m}(n_m, p_m) \\ +\rho_{BS}\gamma_{mBS} \sum\limits_{i_m=n_m-d_m+1}^{n_m} i_m b_{i_m}(n_m, p_m)] \end{array}. \tag{4}$$

The total average repair cost of the system is the sum of the repair cost of each area,

$$E(C_r) = \sum_{m=1}^{M} E(C_{r_m}). \tag{5}$$

Download Cost: When there is a node requesting to download the file in any area m, it is also assumed that the number of storage nodes leaving the system is i, and the number of storage nodes leaving in the area m is i_m. When $0 \leq i_m \leq n_m - h_m$, that is, $l_m \geq h_m$, it can be jointly downloaded by D2D and MBSs. The download cost is $C_{d_m} = N\omega(\rho_{D2Dm} h_m \alpha_m + \rho_{MBS}\frac{2F}{3})$, and the probability is

$$\Pr\{DM\_d\}_m = \frac{1}{\Delta} \sum_{i_m=0}^{n_m-h_m} \frac{1-p_{m(n-i)}}{u_{m(n-i)}} \prod_{j=0,j\neq i_m}^{n_m-h_m} \frac{n-j}{i_m-j}, \tag{6}$$

where, $\mu_{m(_i)} = i\mu_m$, $p_{m(i)} = e^{-\mu_{m(i)}\Delta}$ [14]. When $n_m - h_m + 1 \leq i_m \leq n_m$, that is, $l_m < h_m$, it can only be downloaded jointly by BS and MBSs. The download cost is $C_{d_m} = N\omega(\rho_{BS}\frac{F}{3} + \rho_{MBS}\frac{2F}{3})$, and the probability is

$$\Pr\{BM\_d\}_m = 1 - \Pr\{DM\_d\}_m. \tag{7}$$

So, the average download cost of the area m is

$$\begin{array}{c} E(C_{d_m}) = \frac{N\omega}{F}[(\rho_{MBS}\frac{2F}{3} + \rho_{D2Dm} h_m \alpha_m) \Pr\{DM\_d\}_m \\ +(\rho_{BS}\frac{F}{3} + \rho_{MBS}\frac{2F}{3}) \Pr\{BM\_d\}_m] \\ = N\omega[(\frac{h_m \alpha_m}{F}\rho_{D2Dm} - \frac{1}{3}\rho_{BS}) \Pr\{DM\_d\}_m + \frac{2}{3}\rho_{MBS} + \frac{1}{3}\rho_{BS}] \end{array}. \tag{8}$$

The total average download cost of the system is the sum of the download cost of each area,

$$E(C_d) = \sum_{m=1}^{M} C_{d_m}. \tag{9}$$

The total communication cost of the system is defined as the sum of the average repair cost and the download cost of each area in the system,

$$E(C) = E(C_r) + E(C_d). \tag{10}$$

When the redundancy strategy uses the RFC scheme, the $\frac{F}{3}$ file of each area is decomposed into k data packets (called input symbols). Then use the same RFC with parameter of (n, k, d) to encode the input symbols. Considering uniform allocation, each storage node stores α_{mRFC}-bit data,

$$\alpha_{mRFC} = \frac{F}{3k}. \tag{11}$$

When repairing a node, the number of storage nodes that need to be connected is $d_m RFC = d = c\log(k)$. When downloading the entire file, you need to connect $h_{mRFC} = (1+\varepsilon)k$ storage nodes, so the amount of information that needs to be transferred when downloading is slightly larger than the file size F.

When the redundancy strategy uses the URL-RFC scheme, the $\frac{F}{3}$ file of each area is decomposed into k_m data packets, which are respectively encoded using the RFC with the parameter (n_m, k_m, d_m). Considering uniform allocation, each storage node stores $\alpha_{mURL-RFC}$-bit data,

$$\alpha_{mURL-RFC} = \frac{F}{3k_m}. \tag{12}$$

When repairing a node, the number of storage nodes that need to be connected is $d_m URL - RFC = d_m = c\log(k_m)$. When downloading the entire file, you need to connect $h_{mURL-RFC} = (1+\varepsilon)k_m$ storage nodes, so the amount of information that needs to be transferred when downloading is also slightly larger than the file size F.

When the redundancy strategy uses the MDS scheme, the $\frac{F}{3}$ file of each area is decomposed into k data packets. Then use the same MDS with parameter of (n, k) to encode the input symbols. Considering uniform allocation, each storage node stores α_{mMDS}-bit data,

$$\alpha_{mMDS} = \frac{F}{3k}. \tag{13}$$

When repairing a node, the number of storage nodes that need to be connected is $d_m MDS = k$. When downloading the entire file, you need to connect $h_{mMDS} = k$ storage nodes, so the amount of information that needs to be transferred when downloading is equal to the file size F.

When the redundancy strategy uses the n-fold replication scheme, n copies of the $\frac{F}{3}$ file for each area are backed up. Each storage node stores α_{mCopy}-bit data,

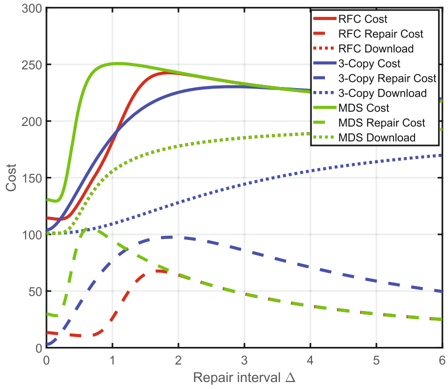
$$\alpha_{mCopy} = \frac{F}{3}. \tag{14}$$

When you repair a node, you only need to connect to one storage node,i.e. $d_{mCopy} = 1$.When downloading the entire file, you need to connect $h_{mCopy} = 1$ storage nodes, so the amount of information that needs to be transferred when downloading is equal to the file size F.

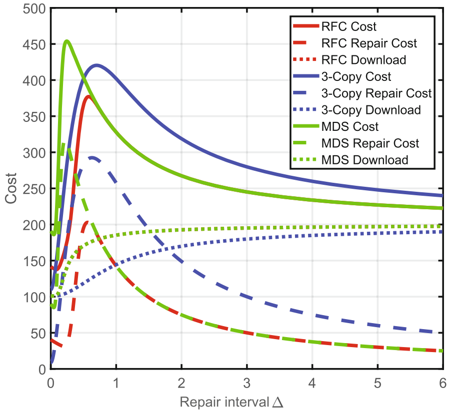
5 Simulation and Results

For the purpose of clearer simulation results, and without loss of generality, we set the public parameters $F = 1$, $M = 3$, $N = 50$, and the repair interval Δ takes 0 to 6.

First, in the case of $\omega = 0.02$, the three areas are respectively encoded using the RFC with the parameter (n, k, d) of $(30, 20, 9)$, the MDS code with the parameter (n, k) of $(30, 20)$, and the 3-copy scheme, we observe the change of the simulation curve when $\mu_1 = \mu_2 = \mu_3$ is 1, 3 respectively, as shown in Fig. 5.



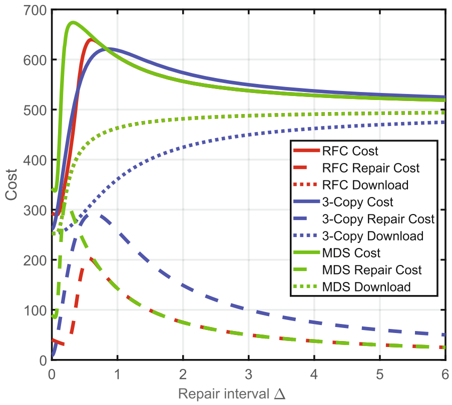
(a) $\mu_1 = \mu_2 = \mu_3 = 1$



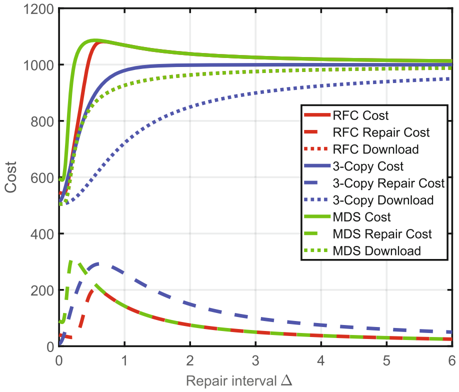
(b) $\mu_1 = \mu_2 = \mu_3 = 3$

Fig. 5. Comparison of communication cost when changing nodes departure rate.

In Fig. 5(a) and (b), $\Delta \to 0$ means instantaneous repair, and $\Delta \to \infty$ means no more repair. As the repair interval Δ increases, the total cost increases first



(a) $\omega = 0.05$

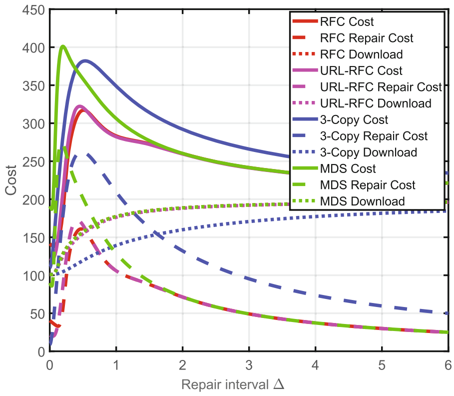


(b) $\omega = 0.1$

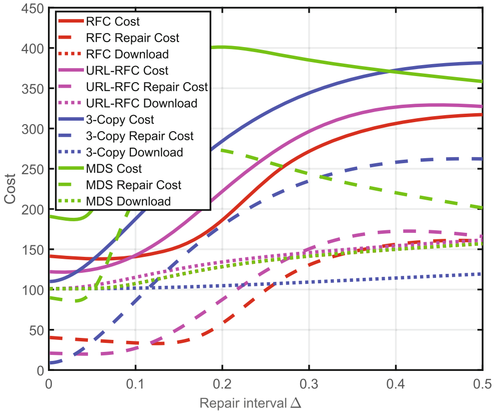
Fig. 6. Comparison of communication cost when changing nodes download rate.

and then decreases, because our cost calculation formula normalize the repair interval. Initially, as the repair interval increases, the number of nodes to be repaired increases each time, so communication cost increases. As the repair interval increases, more and more nodes are lost, but the total average cost is relatively smaller. The RFC has a small locality, and the bandwidth cost of repairing a node is also small, so it has a small repair cost in most repair intervals. Comparing Fig. 5(a) and (b), it can be found that the node leaving rate increases, the number of nodes to be repaired increases in a certain time interval, and the communication cost also increases.

In the case of $\mu_1 = \mu_2 = \mu_3 = 3$, the same coding scheme as in Fig. 5 is used, and the value of ω is changed. Observe the change of the simulation curve when ω is 0.05 and 0.1 respectively, as shown in Fig. 6(a) and (b). When the increase occurs, the download overhead increases, and the overall communication cost



(a) $\varDelta \in (0, 6)$



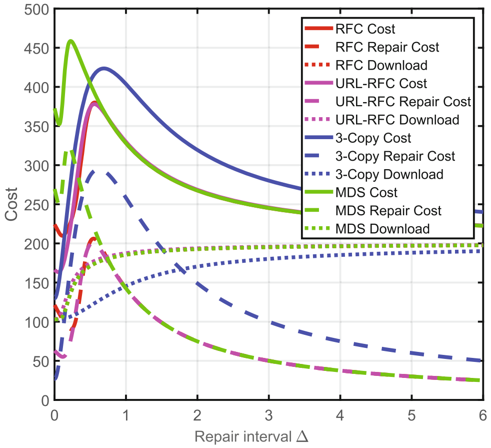
(b) $\varDelta \in (0, 0.5)$

Fig. 7. Comparison of communication cost when nodes departure rates are different, $\mu_1 = 1, \mu_2 = 3, \mu_3 = 5$.

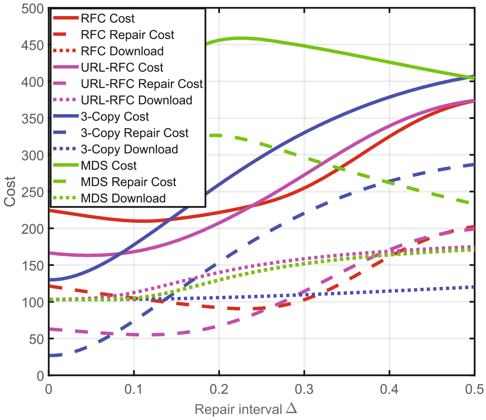
also increases. The repair cost relative to the download cost has less impact on the overall system, resulting in a smaller communication cost of the RFC relative 3-copy scheme, but still superior to the MDS code.

The departure rate of node in the above simulation and the energy cost of transmitting 1-bit of mobile devices in each area are the same, but they should be different in different areas in practical applications. In Fig. 7(a) and (b), different departure rates are set for nodes in the three areas, $\mu_1 = 1, \mu_2 = 3, \mu_3 = 5$. In Fig. 8(a) and (b), the energy transfer energy cost between different nodes is set for three areas, $\rho_{D2D1} = 1, \rho_{D2D2} = 3, \rho_{D2D3} = 5$. The URL-RFC communication cost curve is added to the simulation and compared with the RFC scheme.

In Figs. 7 and 8, when the instantaneous repair is performed, the communication cost of the URL-RFC is lower than that of the other schemes except for



(a) $\Delta \in (0, 6)$



(b) $\Delta \in (0, 0.5)$

Fig. 8. Comparison of communication cost when energy costs are different, $\rho_{D2D1} = 1, \rho_{D2D2} = 3, \rho_{D2D3} = 5$.

the 3-copy scheme. However, as the repair interval increases, the cost of RFC and URL-RFC is smaller than that of the 3-copy scheme and the MDS scheme. Therefore, in the case of heterogeneous mobile devices of the system, the communication cost is optimal using the URL-RFC and RFC schemes, and the use of URL-RFC communication cost is minimal when the repair interval is small.

6 Conclusions

In this paper, we introduce a new type of distributed storage redundancy strategy called repairable fountain code (RFC). The RFC can be used for heterogeneous networks (HeNets) consisting of D2D links for data storage and delivery between devices within the coverage of different micro base stations (MBS). After giving the 3-tier heterogeneous D2D system model, we analyzed the download and repair communication costs of the RFC scheme, the MDS code scheme and the 3-copy scheme. Furthermore, a RFC scheme with unequal repair locality(URL-RFC) is designed and analyzed to reduce the communication cost of the system for the heterogeneity between multiple areas of the system. The simulation results show that the URL-RFC scheme can obtain the lowest communication cost in the case of instantaneous repair, and when the repair interval is larger, the communication cost is greater than the RFC, but it will finally approach to the RFC communication cost curve.

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