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(71) Applicants: **KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY** [SA/SA]; 4700 King Abdullah University of Science and Technology, Thuwal, 23955-6900 (SA). **KING FAHD UNIVERSITY OF PETROLEUM & MINERALS** [SA/SA]; P.O. Box 476, Dhahran, Eastern Province, Dhahran, 34464 (SA).

(72) Inventors: **ARSHAD, Rabe;** P.O. Box 476, Dhahran, Eastern Province, Dhahran, 34464 (SA). **ELSAWY, Hesham;** 4700 King Abdullah University of Science and Technology, Thuwal, 23955-6900 (SA). **SOROUR, Sameh;** P.O. Box 476, Dhahran, Eastern Province, Dhahran, 34464 (SA). **AL-NAFFOURI, Tareq Yousef;** 4700 King Abdullah University of Science and Technology, Thuwal, 23955-6900 (SA). **ALOUINI, Mohamed-Slim;** 4700 King Abdullah University of Science and Technology, Thuwal, 23955-6900 (SA).

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(54) Title: REDUCING HANDOVER SIGNALING THROUGH BASE STATION SKIPPING

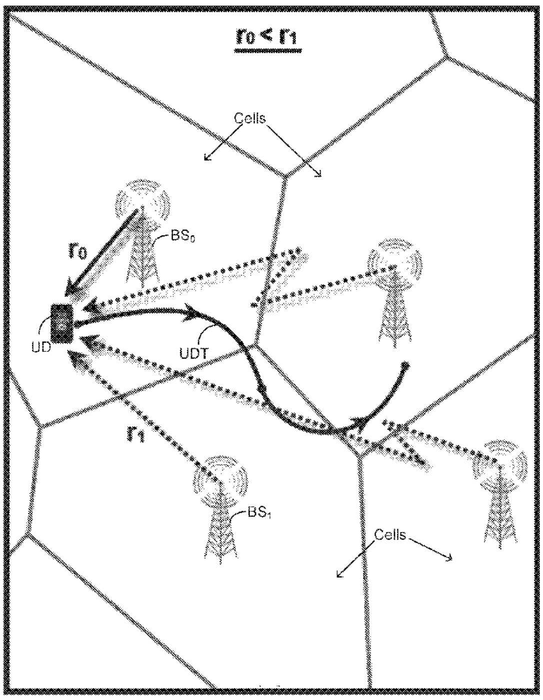

FIG. 1(a)

(57) Abstract: The increase in network densification in order to cope with the ever- increasing capacity demand in 5G causes an increase in the handover rate, which may diminish the capacity gains for mobile users due to HO delays. In highly dense 5G cellular networks, HO delays may neutralize or even negate the gains offered by densification. In order to avoid this problem, it is proposed to, for a user-device travelling above a threshold speed in a network comprising a base station density above a threshold, alternate handover to the best serving base station with skipping handover between base stations, even if they are of the same layer. I. e., based on stochastic geometry, it is proposed to quantify the effect of handover delay on the average user rate in cellular networks and to skip the handover procedure with some BS's along users' trajectories when the handover frequency increases such that the handover delay substantially affects the data throughput.

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REDUCING HANDOVER SIGNALING THROUGH BASE STATION SKIPPING

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to co-pending U.S. provisional application entitled, "Reducing Handover Signaling in Dense Cellular Networks through Base Station Skipping," having serial number 62/313,768, filed March 27, 2016, which is entirely incorporated herein by reference.

TECHNICAL FIELD

[0002] The present disclosure is generally related to handover signaling in cellular networks.

BACKGROUND

[0003] Network densification via base stations (BSs) deployment has been a viable solution for cellular operators to cope with the increasing capacity demand. It is also expected that cellular operators will rely on network densification to fulfill a big chunk of the ambitious fifth generation (5G) requirements. Network densification can be achieved by deploying different types of BSs (e.g., macro, micro, pico, and femto) according to the performance, time, and cost tradeoffs. Deploying more BSs decreases the service area (also referred to as the footprint) of each BS, which improves the spatial spectral utilization and network capacity. However, network densification also increases the handover (HO) rate, which may diminish capacity gains for mobile user-devices due to excessive HO delay. In highly dense 5G cellular networks, HO delays may neutralize or even negate the gains offered by network densification.

SUMMARY

[0004] Embodiments of the present disclosure provide communication link handover systems, apparatuses, and methods. Briefly described, one embodiment of a communication link apparatus includes a processor; a transceiver configured to communicate with a mobile network; and a communication link handover routine executed by the processor to establish a connection with a best serving base station in a first cell of the mobile network, wherein the best serving base station in the first cell is a first base station; after relocating to a second cell of the mobile network, maintain the connection with the first base station in the first cell by skipping connecting with a best serving base station in the second cell; and after relocating to a third cell of the mobile network, establish a connection to a best serving base station in the third cell of the mobile network.

[0005] The present disclosure can also be viewed as providing communication link handover methods. In this regard, one embodiment of such a method, among others, can be broadly summarized by the following steps: determining, by a user-device, a best serving base station within a first cell of a mobile network, wherein the best serving base station is a first base station; requesting, by the user-device, a connection with the first base station in the first cell of the mobile network; after relocating to a second cell of the mobile network, maintaining the connection with the first base station in the first cell by skipping an act of determining a new best serving base station within the second cell, wherein the user-device is closer to a second base station in the second cell than the first base station in the first cell; after relocating to a third cell of the mobile network, determining, by the user-device, the new best serving base station within the third cell of the mobile network,

wherein the new best serving base station within the third cell is a third base station; and requesting a new connection to the third base station within the third cell.

[0006] Such apparatuses and/or methods may also include additional features such as the following: wherein the user-device alternates between performing an act of attempting to connect with its determined best serving base station and skipping the act of attempting to connect with its best serving base station as the user-device traverses cells within the mobile network; responsive to skipping the act of determining/connecting the new best serving base station within the second cell, performing an interference cancellation routine to compensate for interference from the second base station within the second cell of the mobile network; detecting a speed of the user-device, wherein the act of skipping a determination/connection of the new best serving base station is triggered by the detected speed of the user-device; wherein for a defined threshold value, the act of skipping a determination/connection of the new best serving base station within the second cell is triggered by the detected speed being greater than the defined threshold value; determining a current base station intensity, wherein the act of skipping a determination/connection of the new best serving base station is triggered by at least the determined base station intensity; wherein for a defined threshold value, the act of skipping a determination/connection of the new best serving base station within the second cell is triggered by the base station intensity being greater than the defined threshold value; wherein the mobile network comprises a cellular network; and/or wherein the mobile network comprises a wireless local area network.

[0007] Other systems, methods, features, and advantages of the present disclosure will be or become apparent to one with skill in the art upon examination of the following drawings and detailed description. It is intended that all such additional systems, methods, features, and advantages be included within this description, be within the scope of the present disclosure, and be protected by the accompanying claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] Many aspects of the present disclosure can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating the principles of the present disclosure. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views.

[0009] FIGS. 1 and 2 are diagrams illustrating a user-device's trajectory during the skipping of base station handovers in accordance with embodiments of the present disclosure.

[0010] FIG. 3 is a coverage probability plots for best connected (conventional) and blackout (skipping) cases with and without nearest base station (BS) interference cancellation (IC) in accordance with embodiments of the present disclosure.

[0011] FIG. 4 is a plot illustrating handover costs for conventional and base station handover (HO) skipping cases versus user-device velocity in accordance with embodiments of the present disclosure.

[0012] FIGS. 5-7 are plots showing the relationship of user-device throughput with user-device velocity in accordance with embodiments of the present disclosure.

[0013] FIG. 8 is a block diagram of an exemplary user-device in accordance with embodiments of the present disclosure.

DESCRIPTION

[0014] Embodiments of the present disclosure perform or utilize a flexible communication link handover (HO) scheme, referred as HO skipping, to reduce overall HO delay experienced by a high speed mobile user. This scheme allows skipping the HO procedure with some base stations (BSs) along user-devices' trajectories. The performance evaluation and testing of this scheme shows considerable gains in many practical scenarios.

[0015] In general, handover (HO) is the procedure of changing the association of mobile user-devices from one BS to another to maintain their connection to their best serving BS. According to the network objective (e.g., best signal strength, equal BSs' load, low service delay, etc.), different association strategies may be defined to determine the best serving BS. HO is employed to update user-devices' association with mobility to satisfy the defined network objective along their path. An exemplary HO procedure involves signaling overhead between the mobile user-device, the serving BS, the target BS, and the core network elements, which consumes resources and introduces delay. Note that the HO rate increases with the intensity or density of BSs, which imposes higher delays and negatively affects the mobile user-device's throughput. In the case of highly dense cellular networks, the HO delay may become a performance limiting parameter that may neutralize or even negate the gains offered by network densification. Therefore, the HO delay should be carefully incorporated into the design of dense cellular networks to visualize and mitigate its effect. In particular, novel HO strategies are required to reduce the HO delay in order to harvest the foreseen network densification gains.

[0016] In accordance with embodiments of the present disclosure, a flexible HO scheme (denoted as HO skipping) may be deployed, which allows user-devices to skip associating with some of the BSs along their trajectories to reduce the HO delays. That is, a user-device (UD) (e.g., a communication device, such as a cellular mobile phone, etc.) can sacrifice being always best connected to decrease the HO delay and improve the long-term average rate. In accordance with this disclosure, an embodiment of a single HO skipping scheme is described in which a user-device (UD), connected to its best serving BS, skips associating to one subsequent best serving BS on its trajectory and must then reconnect to the following one. This pattern is repeated along the user-device's trajectory such that it alternates between connecting to its best serving BS and skipping the following one, as comparatively illustrated by FIG. 1 and FIG. 2. In particular, FIG. 1(a) represents a best connected case, and FIG. 1(b) shows a blackout case (in which the user-device (UD) skips associating with its best serving BS). In both cases, r_0 represents the distance between a user-device (UD) and its serving BS (BS_0), r_1 represents the distance between the user-device (UD) and its first interfering BS (BS-i) and the curved solid line represents the user-device trajectory (UDT). FIG. 2 represents conventional and skipping HO schemes, where the "red" solid line depicts user-device trajectory across a Voronoi tessellation of a cellular network and the "green" dotted and "blue" solid lines show conventional and skipping HOs respectively.

[0017] In order to draw conclusions on the HO effect and design efficient HO schemes, mathematical paradigms that incorporate the effect of HO delay into the network key performance indicators are utilized. In this regards, recent advances in modeling cellular networks using stochastic geometry can be exploited to develop such mathematical frameworks. Stochastic geometry has succeeded in providing a systematic analytical paradigm to model and design cellular networks.

[0018] In stochastic geometry analysis, the network is abstracted to a convenient point process that maintains a balance between practicality and tractability. The Poisson point process (PPP) is well understood and widely accepted stochastic process due to its tractability and simplicity. Stochastic geometry with BSs modeled as a PPP has enriched the literature with valuable results that enhanced our understanding of the cellular network behavior. However, the effect of HO delay on the performance of dense cellular networks has been overlooked.

[0019] In the present disclosure, the effect of HO delay on the user-device average rate in dense cellular network environments is considered. In particular, a mathematical paradigm is described, based on stochastic geometry that incorporates the HO delay into the rate analysis. It is worth noting that the signal-to-interference-plus-noise-ratio (SINR) dependent expressions are derived based on the stationary PPP analysis. However, it is shown by simulation that the stationary expressions capture the SINR performance of mobile user-devices almost exactly. This implies that averaging over all user-devices' trajectories in all network realizations is equivalent to averaging over all user-devices locations in all network realizations. To this end, the results manifest the prominent negative effect of HO delay on the rate at high intensities of BSs.

[0020] For both the conventional HO and single HO skipping schemes, expressions for the coverage probability and average throughput are derived. The results show that, although BS skipping reduces the average coverage probability of mobile user-devices, it improves their long-term average rate at high speeds and/or high network densities. In various embodiments, a developed model can be used to decide the threshold at which BS skipping is beneficial and quantify the associated performance gains. Accordingly, in certain embodiments, BS skipping can be triggered by a user-device upon a monitored parameter (e.g., device speed or base station intensity) meeting or exceeding a defined threshold. It is important to note that although certain embodiments focus on a single tier cellular network and a single HO skipping scheme, other embodiments may also focus on or address multi-tier cellular networks and multiple HO skipping rules (e.g., skip associating with a best serving BS in consecutive cells).

[0021] In one embodiment, a single-tier downlink cellular network is considered in which the BSs' locations are abstracted via a two dimensional PPP Φ of intensity λ. All BSs are assumed to transmit with the same effective isotropic radiated power (EIRP) denoted by P. A general power-law path loss model with path loss exponent $\eta > 2$ is considered. In addition to the path-loss, transmitted signals experience multi-path fading. In one embodiment, a Rayleigh fading environment is assumed such that the channel power gains have independent exponential distributions. The user-devices associate according to the well-known radio signal strength (RSS) association rules. In the depicted single-tier case, the best RSS association refers to the nearest BS association strategy. The association regions for each BS can be visualized via the Voronoi tessellation diagram shown in FIG. 2. Here, a Voronoi tessellation of an actual cellular network (Macros only) in an urban area with $\lambda = 3$ BS per km^2 is depicted, where the "red" solid line depicts user-device trajectory while the "green" dotted and "blue" solid lines show conventional and skipping HOs respectively. In the conventional scheme, the user-device associates to the BSs {A, B, C, D, E, F, G} and in an embodiment of the skipping scheme, the user-device associates to the BSs {A, C, E, G}.

[0022] Next, an analysis is conducted on a test mobile user-device which is moving on an arbitrary trajectory with velocity v. HO failures are ignored due to blocking and focus is on the coverage probability (defined as the probability that the SINR exceeds a certain threshold 7) and the ergodic rate (defined by Shannon's capacity formula). That is, it is assumed that all BSs can assign a channel to the user-device when this user-device passes within its coverage range. Furthermore, when the user-device is assigned to a certain channel from a generic BS, it is assumed that all other BSs across the spatial domain are reusing the same channel. Due to the HO procedure, a delay time d is imposed on the user-device, at which no useful data is transmitted to it. The delay d represents the time spent in HO signaling between the serving BS, target BS, and core network elements. It is important to note that the delay d may depend on the type of BSs. For instance, the HO delay is small in macro BSs, which are microwave or optically backhauled to the core network. In contrast, the delay d may be more significant in the case of internet protocol (IP) backhauled small BSs (i.e., pico or femto).

[0023] In the conventional HO case, the user-device maintains the best connectivity throughout its trajectory. Hence, when the user-device passes by a certain Voronoi cell, it connects to the BS in the center of that Voronoi cell. This implies that $Pr_0^{-\eta} > Pr_i^{-\eta},\ \forall i \neq 0$ is always satisfied, where r_0 and 77 denote the distances from the user-device to the serving and i^{th} interfering BSs, respectively. The skipping HO scheme is proposed, where the user-device skips associating to one BS after every HO execution. This implies that $Pr_0^{-\eta} > Pr_i^{-\eta}$, $\forall i \neq 0$ is satisfied for 50% of the time and $Pr_1^{-\eta} > Pr_0^{-\eta} > Pr_i^{-\eta}, \quad \forall \notin \{0, 1\}$ is satisfied for the rest of the time, where r_x denotes the distance from the user-device to the skipped BS when it passes within the Voronoi cell of the skipped BS. Thus, in the skipping mode, the user-device alternates between the blackout and best connected state along its trajectory. Here, the event at which the user-device is located within the Voronoi cell of a skipped BS is denoted as blackout event. FIG. 1 shows the best connected and blackout events. FIG. 2 depicts the conventional ("green" dotted line) and skipping ("blue" line) HO schemes for the "red" trajectory.

[0024] The first step in the analysis is to characterize the service distance in the best connected and blackout cases. Note that the service distance is random due to the irregular network topology along with user-device mobility. It is important to characterize the service distance as it highly affects the SINR. Particularly, when the user-device is best connected, the RSS association creates an interference protection of radius r_0 around the user-device. In the blackout case, the user-device keeps its association with the same BS when it enters the Voronoi cell of another BS. Hence, the skipped BS is closer to the user-device than its serving BS (i.e., $r_1 < r_0$). In other words, the skipped BS is located within the radius r_0 and every other interfering BS is located outside r_0. Note that, in the blackout case, r_1 and r_0 are correlated since $r_1 < r_0$. The distribution of the serving BS in the best connected case and the joint distribution of the distances from the user-device to the skipped and serving BS in the blackout case are characterized via the following lemma:

Lemma 1: In a single tier cellular network with intensity λ, the distance distribution between a best connected user-device and its serving BS is given by:

$$f_{r_0}^{(c)}(r) = 2\lambda\pi r e^{-\lambda\pi r^2}, 0 \leq r \leq \infty \quad (1)$$

and the joint distance distribution between a user-device in blackout and its serving and skipped BSs is given by:

$$f_{r_0,r_1}^{(bk)}(x,y) = 4(\pi\lambda)^2 xy e^{-\pi\lambda x^2}; 0 \leq y \leq x \leq \infty \,. \quad (2)$$

Proof: The PDF (probability density function) $f_{r_0}^{(c)}(.)$ is obtained from the null probability of PPP. The joint PDF $f_{r_0,r_1}^{(bk)}(.,.)$ is obtained by writing the conditional CDF (cumulative distribution function) of r_0 given r_x as $\mathbb{P}\{r_0 < x | r_1\} = 1 - e^{-\pi\lambda(x^2 - r_1^2)}$. Then, differentiating the conditional CDF of r_0 with respect to x and multiplying by the marginal PDF of r_1, the joint PDF in Equation (2) is obtained. (Since the user-device is in blackout, r_1 is the distance to the closest BS and r_0 is the distance to the second nearest BS. Hence, the marginal PDF of r_1 is given by $f_{r_1}(y) = 2\lambda\pi y e^{-\lambda\pi y^2}$.)

[0025] The marginal and conditional service distance distributions for the blackout case are characterized by the following corollary:

Corollary 1: The marginal PDF of the distance between the user-device and its serving BS in the blackout case is given by:

$$f_{r_0}^{(bk)}(r) = 2(\lambda\pi)^2 r^3 e^{-\lambda\pi r^2}; 0 \leq r \leq \infty \quad (3)$$

where r_0 represents the distance between the user-device and its serving BS, which is the second nearest BS in the blackout case.

[0026] The conditional (i.e., conditioning on r_0) PDF of the distance between the user-device and the skipped BS in the blackout case is given by:

$$f_{r_1}^{(bk)}(r|r_0) = \frac{2r}{r_0^2}, 0 \leq r \leq r_0 \leq \infty \quad . \tag{4}$$

Proof. The marginal PDF of r_0 is obtained by integrating Equation (2) with respect to y from 0 to r_0 while the conditional PDF of r_1 is obtained by dividing Equation (2) by the marginal distribution of r_0, which is given in Equation (3).

[0027] The coverage probability is defined as the probability that the user-device can achieve a specified SINR threshold T. For the best connected case, the coverage probability is given by

$$\mathcal{C}_c = \mathbb{P}\left\{\frac{Ph_0 r_0{}^{-n}}{\sum_{i\epsilon\phi\backslash b_0} Ph_i r_i^{-\eta} + \sigma^2} \geq T\right\}$$

where b_0 is the serving BS. In the blackout case, the coverage probability is given by

$$\mathcal{C}_{bk} = \mathbb{P}\left\{\frac{Ph_0 r_0{}^{-\eta}}{Ph_1 r_1^{-\eta} + \sum_{i\epsilon\phi\backslash b_0,b_1} Ph_i r_i{}^{-\eta} + \sigma^2} \geq T\right\}$$

where b_0 and b_1 are the serving and the skipped BSs, respectively. By conditioning on r_0 and exploiting the exponential distribution of h_0, the conditional coverage probability in the best connected case can be represented as:

$$\mathcal{C}_c(r_0) = e^{-\frac{T\sigma^2 r_0^{\eta}}{P}} \mathcal{L}I_r\left(\frac{Tr_0^{\eta}}{P}\right) \tag{5}$$

where I_r is the interference from BSs located outside r_0. Similarly, the conditional coverage probability in the blackout case can be represented as:

$$C_{bk}(r_0) = e^{-\frac{T\sigma^2 r_0^\eta}{P}} \mathcal{L}I_1(\frac{Tr_0^\eta}{P})\, \mathcal{L}I_r(\frac{Tr_0^\eta}{P}) \qquad (6)$$

where I_1 is the interference from the skipped BS and I_r is the interference from BSs located outside r_0. The conditional (i.e., conditioning on r_0) Laplace transforms (LTs) of I_r and I_1 are characterized via the following Lemma.

Lemma 2: The Laplace transform of I_r for the best connected and blackout cases is given by:

$$\mathcal{L}I_r(\frac{Tr_0^\eta}{P}) = \exp(-\pi\lambda r_0^2 \vartheta(T,\eta)) \qquad (7)$$

where

$$\vartheta(T,\eta) = T^{2/\eta} \int_{T^{-2/\eta}}^{\infty} \frac{1}{1+\omega^{\eta/2}} d\omega \; .$$

The Laplace transform of I_1 in the blackout case is given by:

$$\mathcal{L}I_1\left(\frac{Tr_0^\eta}{P}\right) = \int_0^{r_0} \frac{1}{1+Tr_0^\eta r^{-\eta}} \frac{2r}{r_0^2} dr \quad . \qquad (8)$$

[0028] In the special case when $\eta = 4$, which is a common path-loss exponent for outdoor environments, the LTs in Lemma 2 can be represented in a closed form as shown in the following corollary.

Corollary 2: For the special case of $\eta = 4$, the LT in (7) reduces to

$$\mathcal{L}I_r\left(\frac{Tr_0^\eta}{P}\right)\Bigg|_{\eta=4} = \exp(-\pi\lambda r_0^2 \sqrt{T} \arctan(\sqrt{T})) \qquad (9)$$

and the LT in (8) reduces to

$$\mathcal{L}I_1\left(\frac{Tr_0^{\eta}}{P}\right)\bigg|_{\eta=4} = 1-\sqrt{T}\arctan\left(\frac{1}{\sqrt{T}}\right)) \quad . \qquad (10)$$

Using Equations (5), (6), and *Lemma* 2, the following theorem for coverage probability is obtained.

Theorem 1: Considering a PPP cellular network with BS intensity λ in a Rayleigh fading environment, the coverage probability for the best connected and blackout user-devices can be expressed by Equations (11) and (12) respectively.

$$\mathcal{C}_c = \int_0^{\infty} 2\pi\lambda x \exp\left(-\frac{T\sigma^2 x^{\eta}}{P} - \pi\lambda x^2\left(1 + T^{2/\eta}\int_{T^{-2/\eta}}^{\infty}\frac{1}{1+\omega^{\eta/2}}d\omega\right)\right)dx$$

(11)

$$\mathcal{C}_{bk} = 4(\lambda\pi)^2\int_0^{\infty} y e^{-Ty^{\eta}\sigma^2-\lambda\pi y^2(\vartheta(T,\eta)+1)}\left(\int_0^{y}\frac{x}{1+Ty^{\eta}x^{-\eta}}dx\right)dy$$

(12)

For $\eta = 4$, Equations (11) and (12) reduce to

$$\mathcal{C}_c|_{\eta=4} = \frac{1}{1+\sqrt{T}\arctan(\sqrt{T})} \qquad (13)$$

$$\mathcal{C}_{bk}|_{\eta=4} = \frac{1-\sqrt{T}\arctan\left(\frac{1}{\sqrt{T}}\right)}{\left(1+\sqrt{T}\arctan(\sqrt{T})\right)^2} \quad . \qquad (14)$$

Proof. The theorem is proven by substituting the LTs from *Lemma 2* and *Corollary 2* in the conditional coverage probabilities in Equations (5) and (6), and then integrating over the PDF of the service distances given in *Lemma 1* and *Corollary 1*.

[0029] In the blackout case, the interference from the skipped BS (i.e., I_1) may be overwhelming to the SINR. Hence, interference cancellation techniques could be employed to improve the coverage probability. In this case, the interfering signal from the skipped BS is detected, demodulated, decoded and then subtracted from the received signal. The coverage probability for blackout user-device is given by the following theorem.

Theorem 2: Considering a PPP cellular network with BS intensity λ in a Rayleigh fading environment, the coverage probability for blackout user-devices with interference cancellation capabilities can be expressed as

$$\mathcal{C}_{bk}^{(IC)} = \frac{1}{(1+\vartheta(T,\eta))^2} \qquad (15)$$

where $\vartheta(T,\eta)$ is defined in *Lemma 2.* For the case of $\eta = 4$, Equation (15) reduces to

$$\mathcal{C}_{bk}^{(IC)}\Big|_{\eta=4} = \frac{1}{\left(1+\sqrt{T}\arctan(\sqrt{T})\right)^2} \quad . \qquad (16)$$

Proof. The theorem is obtained using the same methodology for obtaining Equation (14) but with eliminating I_1 from Equation (6). The coverage probability plots for best connected (conventional) and blackout (skipping) cases with and without nearest BS interference cancellation (IC) are shown in FIG. 3 (at $\eta = 4$). It can be observed that the simulation results (which are obtained for mobile user-devices) are in accordance with the analysis which validates our model. The figure shows the cost of skipping in terms of coverage probability degradation. Note that the user-devices in the BS skipping scheme alternate between the blackout and best connected cases for which only one BS skipping at a time is allowed in an embodiment of the present disclosure, among others. Hence, a user-device in the skipping model would spend 50% of the time with the blackout coverage and 50% of the time in best connected coverage in one embodiment.

[0030] The figure also shows that interference cancellation highly improves the SINR when compared to the blackout case without interference cancellation. Note that, although the expressions in *Theorems 1* and 2 are obtained using stationary PPP analysis, they conform with the simulations done with mobile user-devices. Below, the effect of BS skipping on the user-device rate is described.

[0031] User-device mobility effect and compute handover rates for both conventional and skipping schemes are described in the present disclosure. The handover rates are used to quantify the handover delay per unit time $D_{H}o$ (i.e., time consumed in HO per time unit). $D_{H}o$ can be expressed as a function of HO rate (HOR) and HO delay *d* as shown below:

$$D_{HO} = HOR * d \quad . \tag{17}$$

[0032] Following Equation [9], the HO rate in a single tier network can be expressed as

$$H(v) = \frac{4v}{\pi}\sqrt{\lambda} \quad . \tag{18}$$

[0033] Consequently, the handover delay $D_{H}o$ for both conventional and skipping cases can be expressed as

$$D_{HO}^{(c)} = \frac{4v}{\pi}\sqrt{\lambda d} \tag{19}$$

$$D_{HO}^{(sk)} = \frac{2v}{\pi}\sqrt{\lambda d} \tag{20}$$

where $D_{HO}^{(c)}$ and $D_{HO}^{(sk)}$ are the HO costs for conventional and skipping cases respectively. Note that the handover cost for the skipping case is half of the conventional case because the user-device skips half of the handovers across the trajectory. Assuming HO delay of 0.7 seconds for macro BSs and 2 seconds for IP-backhauled small cells, the handover cost is plotted in FIG. 4. In particular, FIG. 4

shows DHO plots for conventional and HO skipping cases vs. user-device velocity (Kmph) for λ = 30BS/km^2.

[0034] An expression for average throughput for HO skipping case is derived next. In order to calculate the throughput, the control overhead is omitted and it is assumed that the control overhead consumes a fraction u_c of overall network capacity which is 0.3 as per 3GPP Release 11. Thus, the average throughput (AT) can be expressed as

$$AT = W\mathcal{R}(1 - u_c)(1 - D_{HO}) \qquad (21)$$

where W is the overall bandwidth of the channel and 31 is the average spectral efficiency (i.e., nats/sec/Hz). The average spectral efficiency can expressed in terms of the coverage probability as

$$\mathcal{R} \overset{(a)}{=} \int_0^\infty \mathbb{P}\{\ln(1 + SINR) > z\}dz \qquad (22)$$

$$\overset{(b)}{=} \int_0^\infty \frac{\mathbb{P}\{SINR > t\}}{t+1} dt \qquad (23)$$

where (a) follows as shown because ln(1 + SINR) is a positive random variable and (b) follows as shown by the change of variables $t = e^z - 1$. For brevity, expressions for 31 for general η are not shown as they can be directly obtained by substituting the coverage probability from Theorem 1 and Theorem 2 in Equation (22). In the special case of $\eta = 4$, the average spectral efficiency for the conventional and blackout cases are given by

$$\mathcal{R}_c = \int_0^\infty \frac{1}{(1+t)(1-\sqrt{t}\arctan(\sqrt{t}))} dt \qquad (24)$$

$$\simeq 1.49 \text{ nats/sec/Hz}$$

and

$$\mathcal{R}_{bk} = \int_0^\infty \frac{1-\sqrt{t}\arctan\left(\frac{1}{\sqrt{t}}\right)}{(1+t)(1+\vartheta(t,4))^2} dt \quad (25)$$

$$\overset{(c)}{\simeq} 0.21 \text{ nats/sec/Hz}$$

$$\overset{(d)}{\simeq} 0.66 \text{ nats/sec/Hz}$$

where (c) and (d) are for blackout cases without and with interference cancellation, respectively.

[0035] In the HO skipping case, the user-device alternates between the best connection and blackout case along its trajectory. More particularly, the user-device in HO skipping spent 50% of the time as a blackout user-device and 50% of the time as a best connected user-device. Hence, the average spectral efficiency for user-devices in HO skipping is given by

$$\mathcal{R}_s = \frac{\mathcal{R}_c + \mathcal{R}_{bk}}{2} \simeq 1.07 \text{ nats/sec/Hz} \quad (26)$$

[0036] Next, the developed analytical model is used to evaluate the performance of HO skipping in terms of user-devices throughput. The following parameters are used to conduct such an analysis: transmission powers of all BSs are considered to be unity; channel bandwidth (W) is considered to be 10MHz; control overhead is assumed to be 0:3 for the conventional case and 0:15 for the skipping case; path loss exponent is considered to be $\eta = 4$; different values of λ are considered to mark the nominal speed at which HO skipping is effective; a nearest BS interference cancellation technique is assumed; and analysis is conducted for d = 0.7 & 2 seconds.

[0037] As depicted in FIGS. 5-7, performance gain with HO skipping depends on BS intensity. In particular, in FIG. 5,user-device throughput (Mbps) vs. user-device velocity (Kmph) is plotted for λ = 30 and W = 10MHz; in FIG. 6, user-device throughput (Mbps) vs. user-device velocity (Kmph) is plotted for λ = 50 and W = 10MHz; and in FIG. 7, user-device throughput (Mbps) vs. user-device velocity (Kmph) is plotted for λ = 70 and W = 10MHz. Note that the improved performance of the HO skipping stems from the increased HO delay with the BS intensity. From the statistics shown in FIGS. 5-7, for the HO skipping case, it can be observed that the user-device throughput experience tends to improve with the increase in user-device velocity. For instance, when $\lambda = 70\text{BS/Km}^2$, the skipping HO scheme outperforms the conventional HO scheme once the user-device speed exceeds 40 Kmph and 110 Kmph for d = 2 and 0.7 seconds respectively. Correspondingly, in one embodiment, an HO skipping scheme may be performed by a user-device at monitored detected parameter(s) that meet or exceed $\lambda = 70\text{BS/Km}^2$, user-device speed = 40 Kmph, or a combination thereof.

[0038] In brief, the present disclosure presents a study for the effect of HO delays on the user-device average rate in single-tier dense cellular networks using tools from stochastic geometry. In accordance with embodiments of the present disclosure, a single HO skipping scheme is proposed to reduce the negative effect of this delay. Tractable mathematical expressions for the coverage probabilities and average throughput for both the conventional HO and HO skipping scenarios are described, which reduce to closed-forms in some special cases. Mathematical paradigm and numerical results demonstrate the merits of the proposed HO skipping strategy in many practical scenarios. This new HO strategy enhances the Quality of Service (QOS) for service providers and helps to offer a better service experience to both voice and data subscribers. In various embodiments, HO skipping solutions may be extended to multi-tier cellular networks. Accordingly, the performance of multiple HO skipping and optimizing a number of skipped BSs may be evaluated and utilized to maximize the average rate performance in multi-tier or single tier cellular networks in various embodiments.

[0039] Such a scheme can be utilized for highly dense or metropolitan areas with high user-device mobility. It can be applied to both cellular (4G & 5G) and Wi-Fi networks. An exemplary scheme is described in a paper entitled, "Handover Management in Dense Cellular Networks: A Stochastic Geometry Approach," by Rabe Arshad, *et al.* which is incorporated herein in its entirety. In this paper, the inventors of the present disclosure present an analytical paradigm, based on stochastic geometry, to quantify the effect of HO delay on the average user-device rate in cellular networks. As discussed, embodiments of systems, methods, and apparatuses of the present disclosure utilize or make use of the disclosed scheme(s).

[0040] Embodiments of the present disclosure can be implemented in hardware, software, firmware, or a combination thereof. Accordingly, certain embodiment(s) are implemented in software or firmware that is stored in a memory and that is executed by a suitable instruction execution system. If implemented in hardware, certain embodiments can be implemented with any or a combination of the following technologies, which are all well known in the art: a discrete logic circuit(s) having logic gates for implementing logic functions upon data signals, an application specific integrated circuit (ASIC) having appropriate combinational logic gates, a programmable gate array(s) (PGA), a field programmable gate array (FPGA), efc.

[0041] In one embodiment, a user-device may include a processor component or processor(s) for controlling the various components and functions of the user-device. The user-device may also include multiple RF transceivers such as, for instance, a WiFi, WiMAX, WLAN transceiver and/or a cellular transceiver.

[0042] For example, a WLAN transceiver may be operable to communicate with an IP network access point using one or more of the 802.1 1 wireless transmission protocols. Upon connection with an IP network access point, the user-device may exchange IP data with servers or other computers that are connected with or communicable with the Internet via a wireless network. This may include a base station.

[0043] Additionally, a cellular transceiver may be operable to communicate with a mobile network for both circuit-switched voice and IP data communication. On the circuit-switched voice side, the mobile network may be based on GSM, CDMA, or other communication protocols while on the IP data side, the mobile network may be based on, for example, GPRS, EDGE, EV-DO, HSPA-D, HSPA-U, LTE, UMTS-WCDMA, UMTS-TDD, eHRPD etc.

[0044] The user-device may further include data storage, software applications, various user interface(s), and its own communication link handover logic/circuitry. The data storage may include, for example, one or more types of memory devices including, but not limited to, flash memory usable for ROM, RAM, PROM, EEPROM, and cache. The software applications may include, for example, one or more software applications executable on or by the processors) including, but not limited to, web browsers, email applications, application specific data and/or audio/video applications, communication link handover applications or routines, etc. The user interface(s) may include, for example, a display, a touchscreen for softkey input, speaker(s), microphone(s), a keyboard for hard-key input, and one or more buttons. The communication link handover circuitry may be configured to perform one or more operations including establishing and executing a handover profile or pattern based at least in part on user-device parameters), network parameters), etc.

[0045] With reference to FIG. 8, shown is a schematic block diagram of the user-device (UD) according to an embodiment of the present disclosure. The user-device 800 may represent a mobile communication device (e.g. a smartphone, tablet, computer, etc.). An exemplary user-device 800 includes at least one processor circuit or component, for example, having a processor 803 and a memory 806, both of which are coupled to a local interface 809. The local interface 809 may comprise, for example, a data bus with an accompanying address/control bus or other bus structure as can be appreciated.

[0046] In some embodiments, the user-device 800 can include one or more network interfaces for communicating with communication networks, such as a mobile network. The network interface may comprise, for example, a cellular and/or wireless transceiver 810. As one skilled in the art can appreciate, various wireless protocols may be used in the various embodiments of the present disclosure.

[0047] Stored in the memory 806 are both data and several components that are executable by the processor 803. In particular, stored in the memory 806 and executable by the processor 803 are a communication link handover routine 815 and potentially other applications. Also stored in the memory 806 may be a data store 812 and other data. In addition, an operating system may be stored in the memory 806 and executable by the processor 803.

[0048] It is understood that there may be other applications that are stored in the memory 806 and are executable by the processor 803 as can be appreciated. Where any component discussed herein is implemented in the form of software, any one of a number of programming languages may be employed such as, for example, C, C++, C#, Objective C, Java®, JavaScript®, Perl, PHP, Visual Basic®, Python®, Ruby, Flash®, or other programming languages.

[0049] A number of software components are stored in the memory 806 and are executable by the processor 803. In this respect, the term "executable" means a program file that is in a form that can ultimately be run by the processor 803. Examples of executable programs may be, for example, a compiled program that can be translated into machine code in a format that can be loaded into a random access portion of the memory 806 and run by the processor 803, source code that may be expressed in proper format such as object code that is capable of being loaded into a random access portion of the memory 806 and executed by the processor 803, or source code that may be interpreted by another executable program to generate instructions in a random access portion of the memory 806 to be executed by the processor 803, etc. An executable program may be stored in any portion or component of the memory 806 including, for example, random access memory (RAM), read-only memory (ROM), hard drive, solid-state drive, USB flash drive, memory card, optical disc such as compact disc (CD) or digital versatile disc (DVD), floppy disk, magnetic tape, or other memory components.

[0050] The memory 806 is defined herein as including both volatile and nonvolatile memory and data storage components. Volatile components are those that do not retain data values upon loss of power. Nonvolatile components are those that retain data upon a loss of power. Thus, the memory 806 may comprise, for example, random access memory (RAM), read-only memory (ROM), hard disk drives, solid-state drives, USB flash drives, memory cards accessed via a memory card reader, floppy disks accessed via an associated floppy disk drive, optical discs accessed via an optical disc drive, magnetic tapes accessed via an appropriate tape drive, and/or other memory components, or a combination of any two or more of these memory components. In addition, the RAM may comprise, for example, static random access memory (SRAM), dynamic random access memory (DRAM), or magnetic random access memory (MRAM) and other such devices. The ROM may comprise, for example, a programmable read-only memory (PROM), an erasable programmable read-only memory (EPROM), an electrically erasable programmable read-only memory (EEPROM), or other like memory device.

[0051] Also, the processor 803 may represent multiple processors 803 and/or multiple processor cores and the memory 806 may represent multiple memories 806 that operate in parallel processing circuits, respectively. In such a case, the local interface 809 may be an appropriate network that facilitates communication between any two of the multiple processors 803, between any processor 803 and any of the memories 806, or between any two of the memories 806, etc. The local interface 809 may comprise additional systems designed to coordinate this communication, including, for example, performing load balancing. The processor 803 may be of electrical or of some other available construction.

[0052] Although the communication link handover routine 815 and other various components described herein may be embodied in software or code executed by general purpose hardware as discussed above, as an alternative the same may also be embodied in dedicated hardware or a combination of software/general purpose hardware and dedicated hardware. If embodied in dedicated hardware, each can be implemented as a circuit or state machine that employs any one of or a combination of a number of technologies. These technologies may include, but are not limited to, discrete logic circuits having logic gates for implementing various logic functions upon an application of one or more data signals, application specific integrated circuits (ASICs) having appropriate logic gates, field-programmable gate arrays (FPGAs), or other components, etc. Such technologies are generally well known by those skilled in the art and, consequently, are not described in detail herein.

[0053] It should be emphasized that the described embodiments are merely possible examples of implementations, merely set forth for a clear understanding of the principles of the present disclosure. Many variations and modifications may be made to the described embodiment(s) without departing substantially from the principles of the present disclosure. All such modifications and variations are intended to be included herein within the scope of this disclosure.

CLAIMS:

1. A handover method comprising:

determining, by a user-device, a best serving base station within a first cell of a mobile network, wherein the best serving base station is a first base station;

requesting, by the user-device, a connection with the first base station in the first cell of the mobile network;

after relocating to a second cell of the mobile network, maintaining the connection with the first base station in the first cell by skipping an act of determining a new best serving base station within the second cell, wherein the user-device is closer to a second base station in the second cell than the first base station in the first cell;

after relocating to a third cell of the mobile network, determining, by the user-device, the new best serving base station within the third cell of the mobile network, wherein the new best serving base station within the third cell is a third base station; and

requesting a new connection to the third base station within the third cell.

2. The method of claim 1, wherein the user-device alternates between performing an act of attempting to connect with its determined best serving base station and skipping the act of attempting to connect with its best serving base station as the user-device traverses cells within the mobile network.

3. The method of claim 1, further comprising responsive to skipping the act of determining the new best serving base station within the second cell, performing an interference cancellation routine to compensate for interference from the second base station within the second cell of the mobile network.

4. The method of claim 1, further comprising detecting a speed of the user-device, wherein the act of skipping a determination of the new best serving base station is triggered by the detected speed of the user-device.

5. The method of claim 4, wherein for a defined threshold value, the act of skipping a determination of the new best serving base station within the second cell is triggered by the detected speed being greater than the defined threshold value.

6. The method of claim 1, further comprising determining a current base station intensity, wherein the act of skipping a determination of the new best serving base station is triggered by at least the determined base station intensity.

7. The method of claim 6, wherein for a defined threshold value, the act of skipping a determination of the new best serving base station within the second cell is triggered by the base station intensity being greater than the defined threshold value.

8. The method of claim 1, wherein the mobile network comprises a cellular network.

9. The method of claim 1, wherein the mobile network comprises a wireless local area network.

10. An apparatus comprising:

a processor;

a transceiver configured to communicate with a mobile network; and

a communication link handover routine executed by the processor to:

establish a connection with a best serving base station in a first cell of the mobile network, wherein the best serving base station in the first cell is a first base station;

after relocating to a second cell of the mobile network, maintain the connection with the first base station in the first cell by skipping connecting with a best serving base station in the second cell; and

after relocating to a third cell of the mobile network, establish a connection to a best serving base station in the third cell of the mobile network.

11. The apparatus of claim 10, wherein the apparatus alternates between establishing a connection with best serving base station and skipping establishing the connection with the best serving base station as the user-device travels across cells within the mobile network.

12. The apparatus of claim 10, wherein the communication link handover routine is programmed to determine a current base station intensity, wherein the act of skipping connecting with the best serving base station in the second cell is triggered by at least the determined base station intensity, wherein for a defined threshold value, the act of skipping a connecting with the best serving base station in the second cell is triggered by the base station intensity being greater than the defined threshold value.

13. The apparatus of claim 10, wherein the communication link handover routine is programmed to responsive to skipping connecting with the best serving base station in the second cell, performing an interference cancellation routine to compensate for interference from the best serving base station in the second cell of the mobile network.

14. The apparatus of claim 10, wherein the communication link handover routine is programmed to detect a speed of the apparatus, wherein the act of skipping connecting with the best serving base station in the second cell is triggered by the detected speed of the apparatus.

15. The apparatus of claim 14, wherein for a defined threshold value, the act of skipping connecting with the best serving base station in the second

cell is triggered by the detected speed being greater than the defined threshold value.

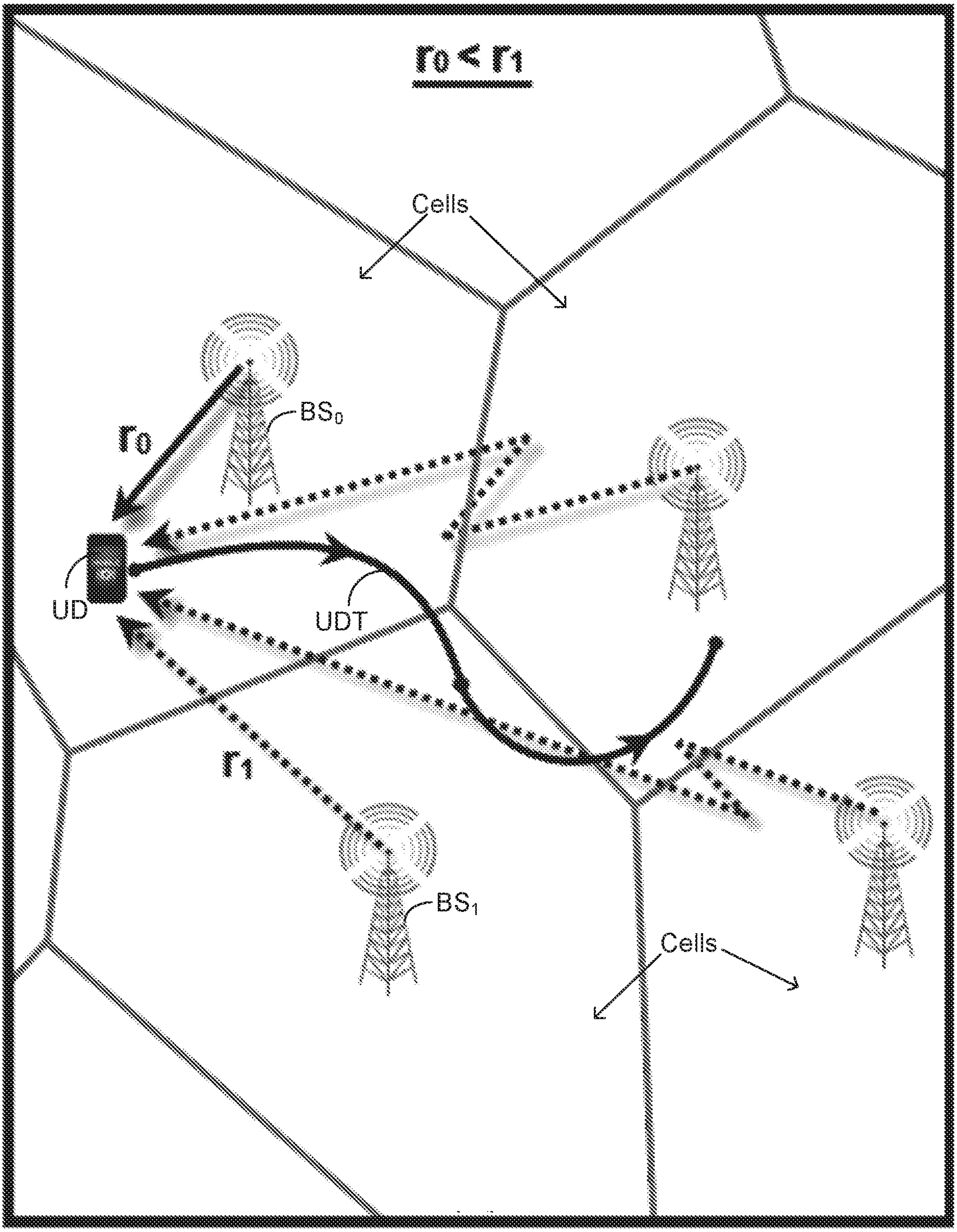

FIG. 1(a)

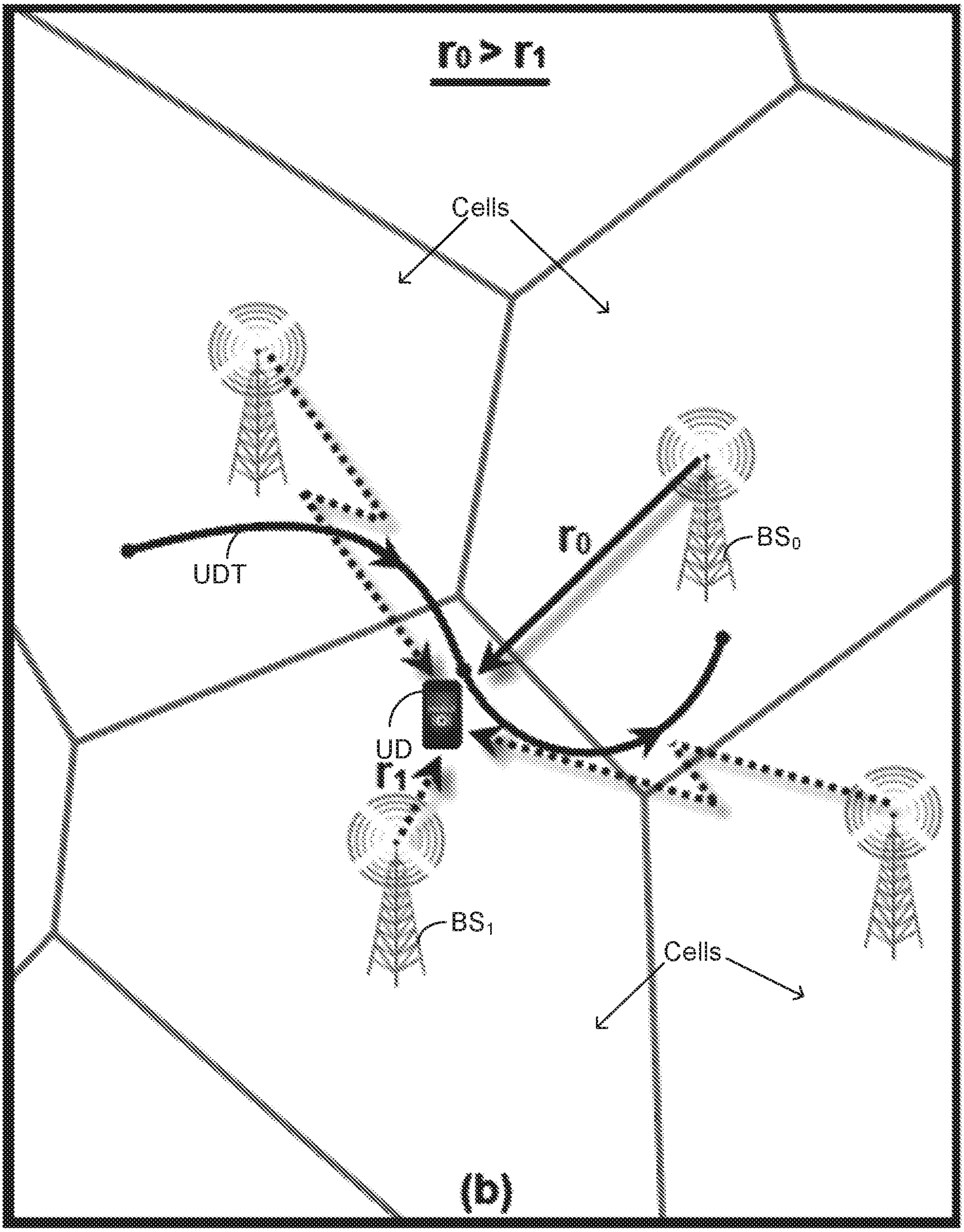

FIG. 1(b)

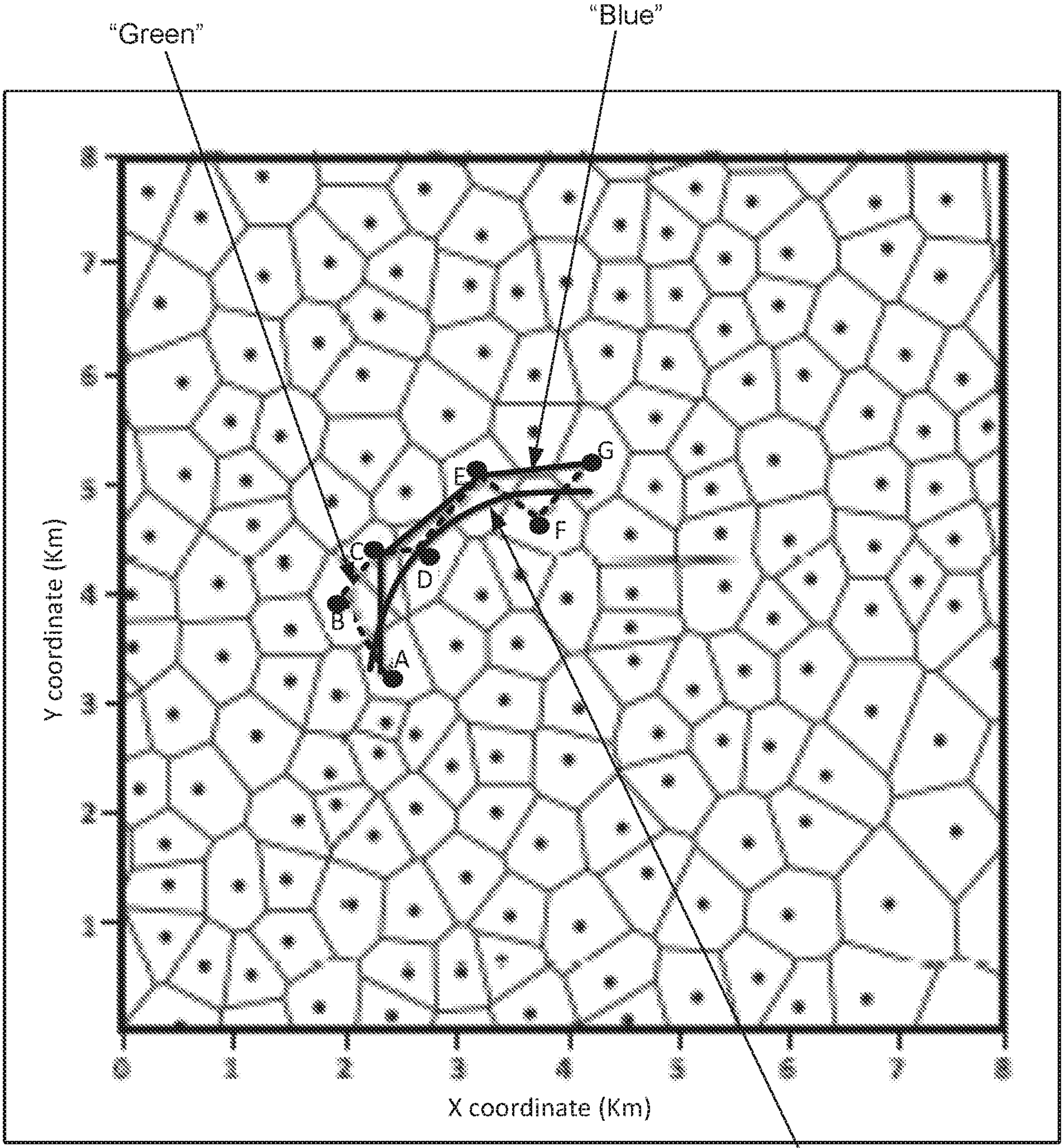
"Green"
"Blue"
G
E
C
D
F
B
A
Y coordinate (Km)
X coordinate (Km)
0
1
2
3
4
5
6
7
8
"Red"

FIG. 2

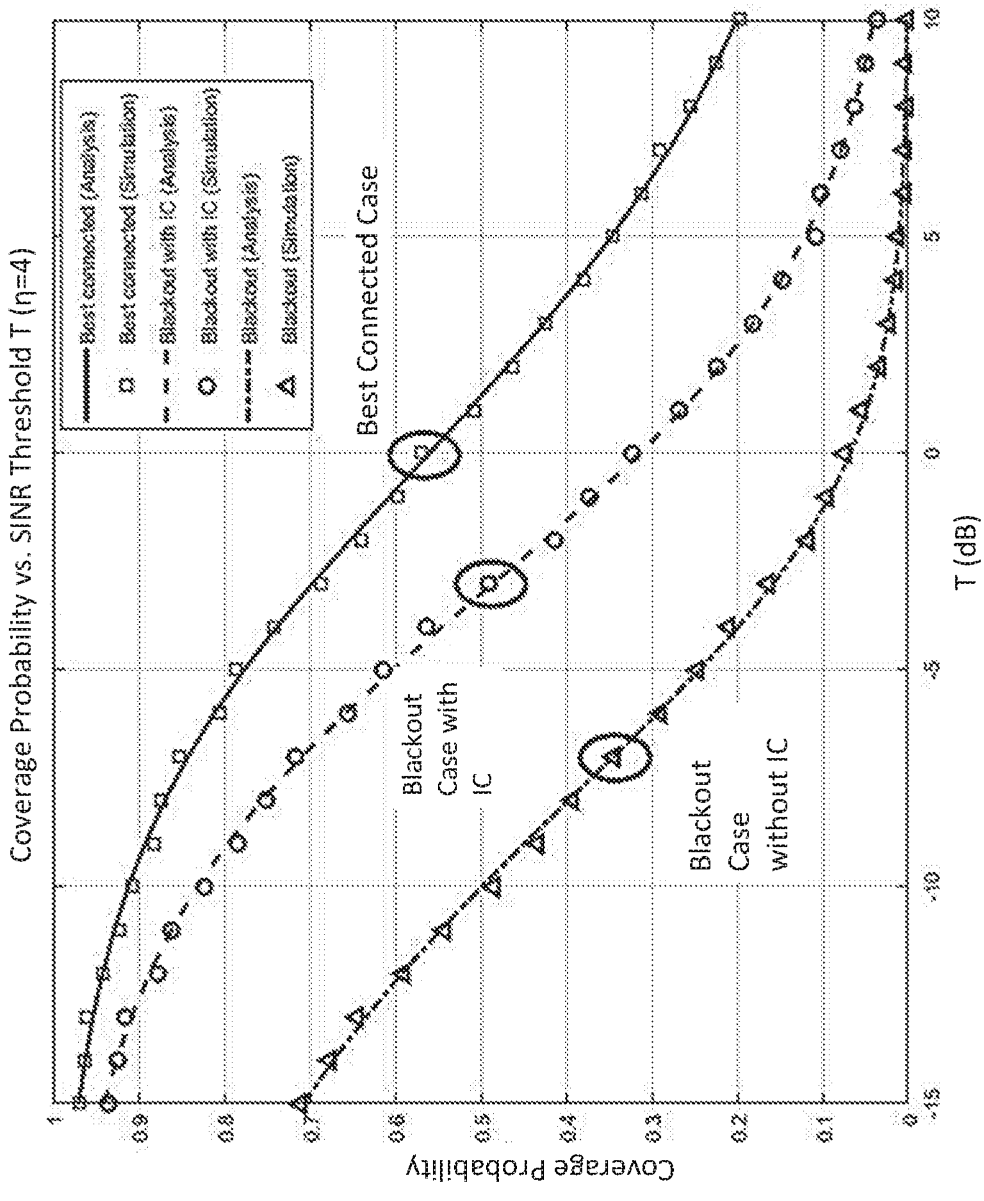
Coverage Probability vs. SINR Threshold T (η=4)
Best connected (Analysis)
Best connected (Simulation)
Blackout with IC (Analysis)
Blackout with IC (Simulation)
Blackout (Analysis)
Blackout (Simulation)
Best Connected Case
Blackout Case with IC
Blackout Case without IC
Coverage Probability
T (dB)
-15
-10
-5
0
5
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

FIG. 3

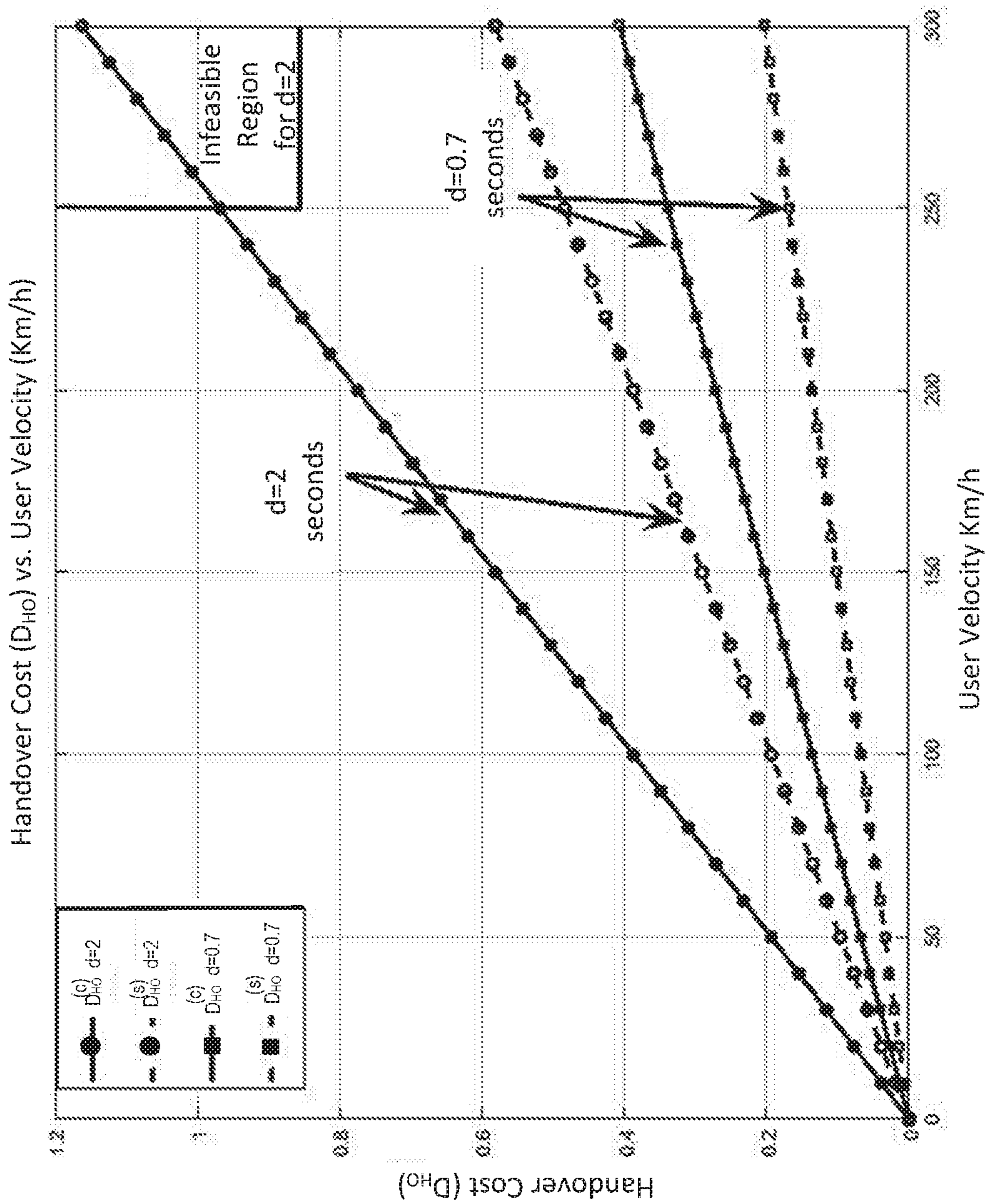
Handover Cost (D_HO) vs. User Velocity (Km/h)
D_HO^(c) d=2
D_HO^(s) d=2
D_HO^(c) d=0.7
D_HO^(s) d=0.7
Infeasible Region for d=2
d=2 seconds
d=0.7 seconds
Handover Cost (D_HO)
User Velocity Km/h
0
0.2
0.4
0.6
0.8
1
1.2
0
50
100
150
200
250
300

FIG. 4

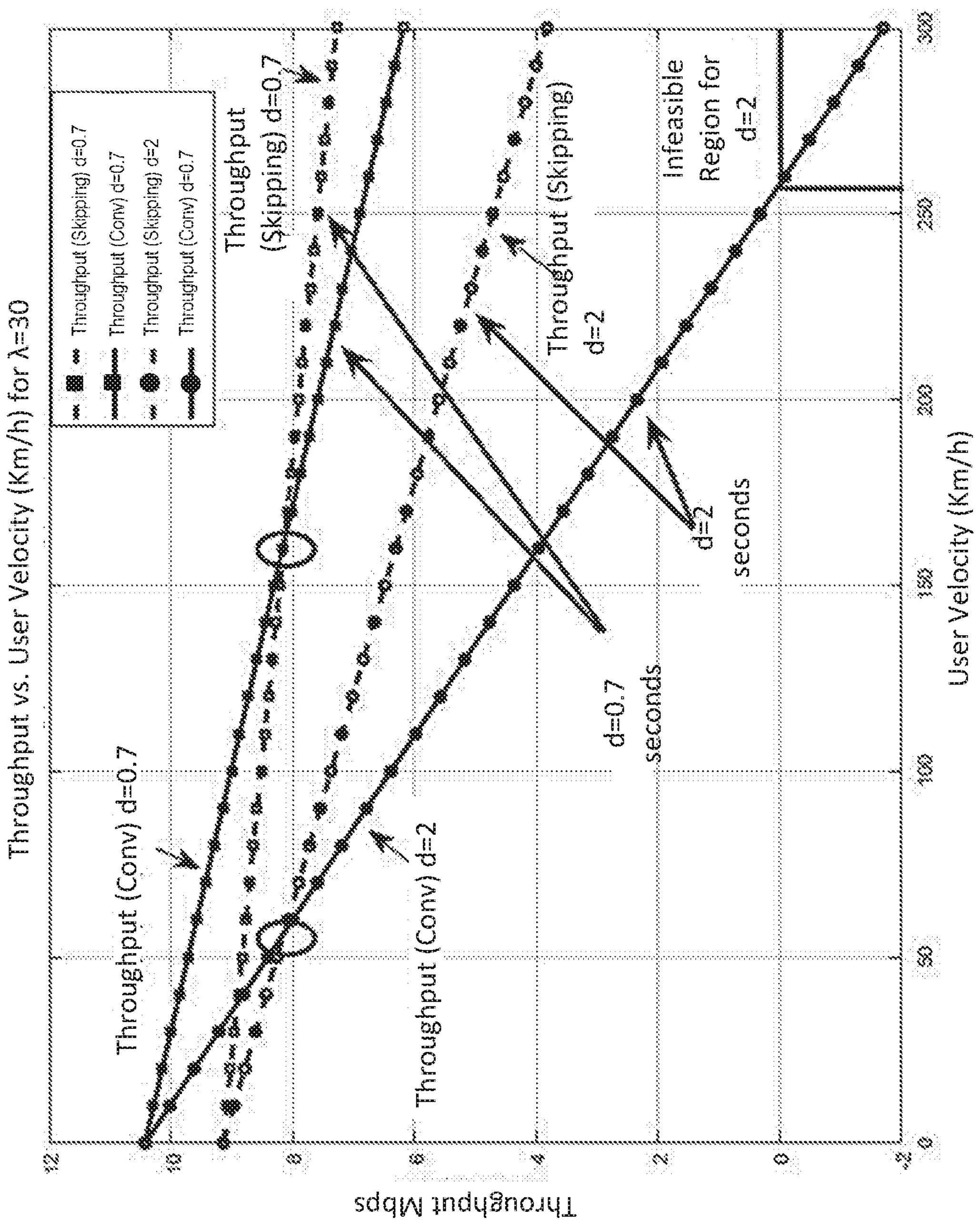
Throughput vs. User Velocity (Km/h) for λ=30
Throughput (Skipping) d=0.7
Throughput (Conv) d=0.7
Throughput (Skipping) d=2
Throughput (Conv) d=0.7
Throughput (Conv) d=0.7
Throughput (Skipping) d=0.7
Throughput (Skipping) d=2
Throughput (Conv) d=2
d=0.7 seconds
d=2 seconds
Infeasible Region for d=2
Throughput Mbps
User Velocity (Km/h)
12
10
8
6
4
2
0
-2
0
50
100
150
200
250
300

FIG. 5

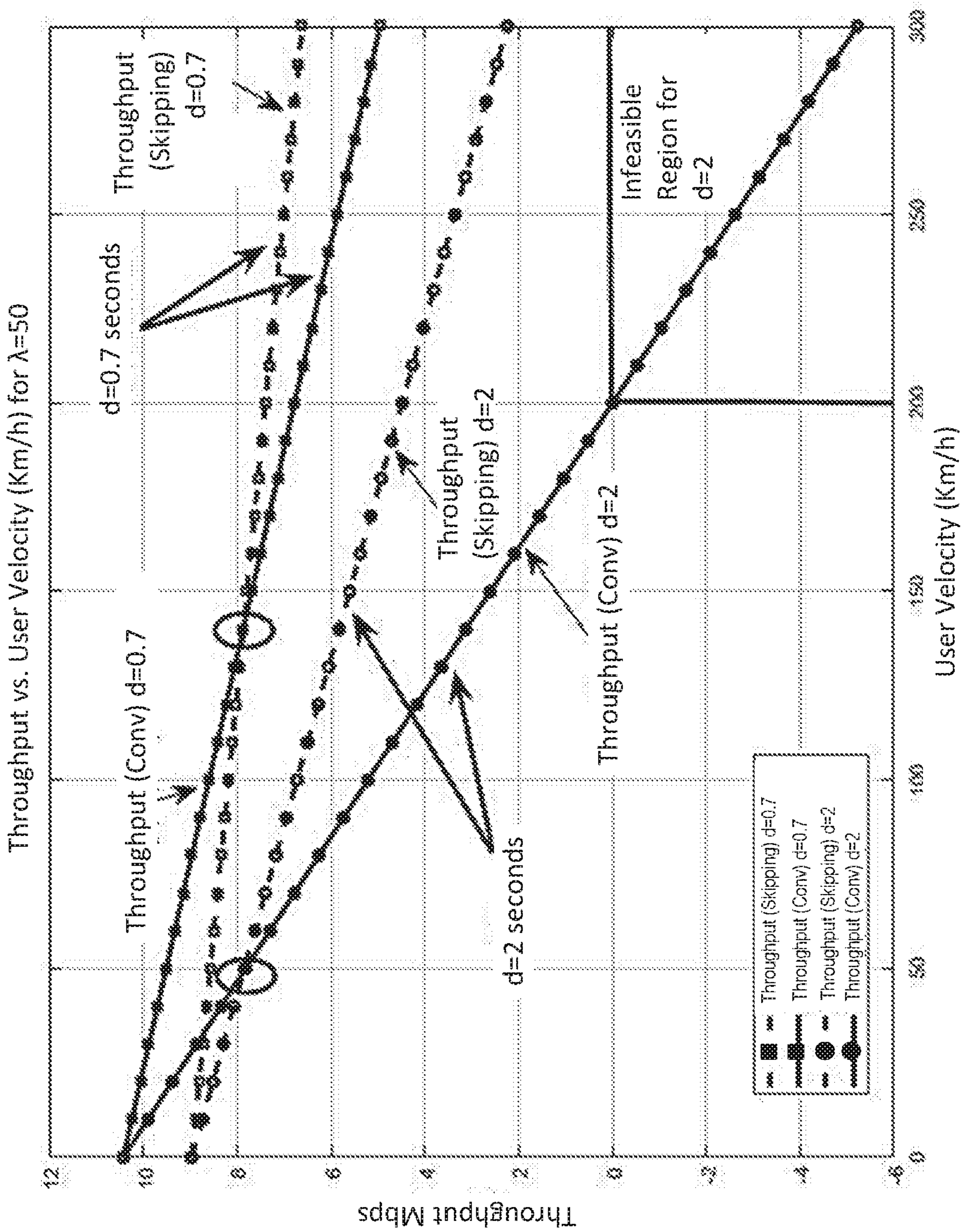
Throughput vs. User Velocity (Km/h) for λ=50
Throughput Mbps
User Velocity (Km/h)
12
10
8
6
4
2
0
-2
-4
-6
0
50
100
150
200
250
300
Throughput (Conv) d=0.7
Throughput (Skipping) d=0.7
d=0.7 seconds
Throughput (Skipping) d=2
Throughput (Conv) d=2
d=2 seconds
Infeasible Region for d=2
Throughput (Skipping) d=0.7
Throughput (Conv) d=0.7
Throughput (Skipping) d=2
Throughput (Conv) d=2

FIG. 6

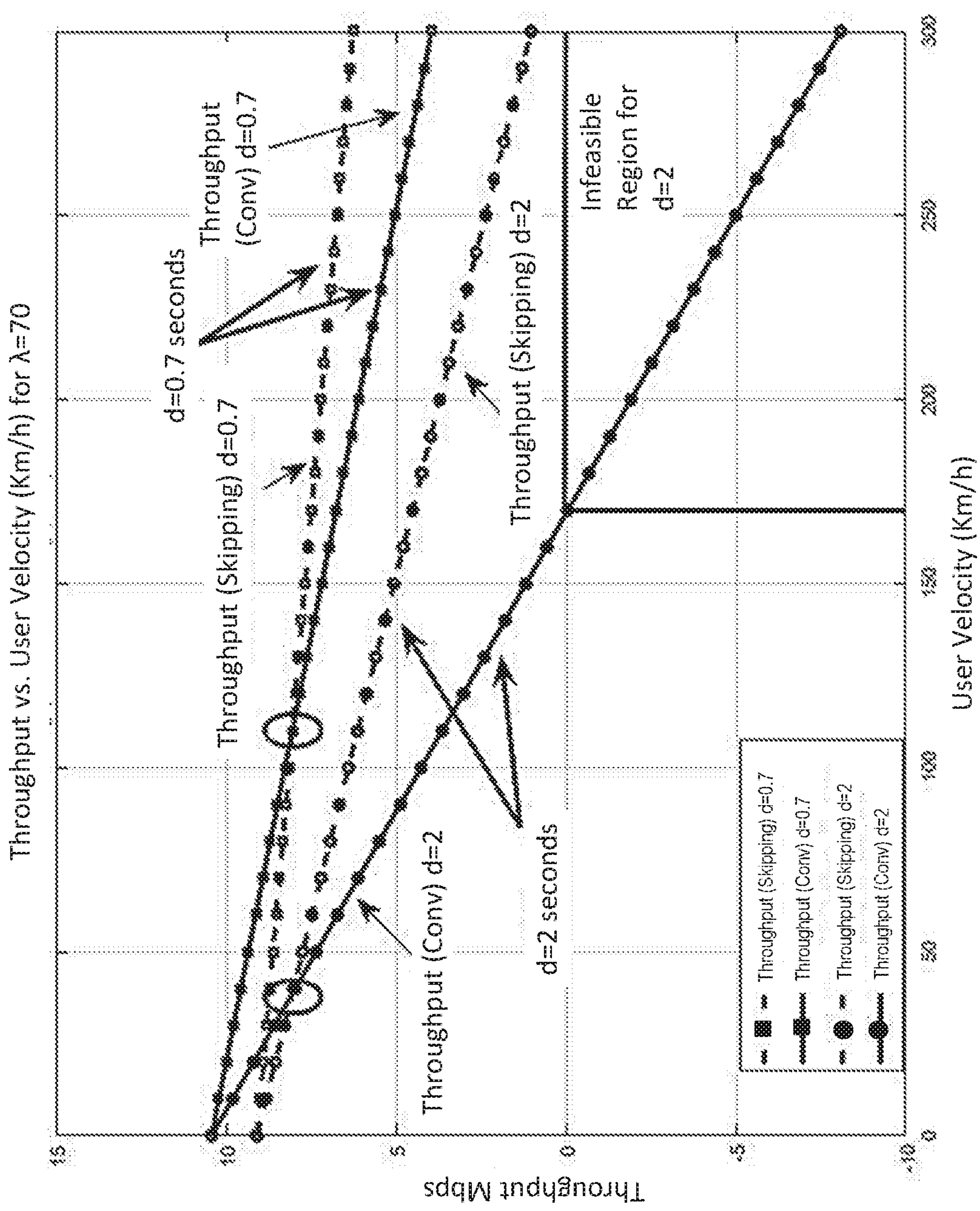
Throughput vs. User Velocity (Km/h) for λ=70
Throughput Mbps
User Velocity (Km/h)
15
10
5
0
-5
-10
0
50
100
150
200
250
300
Throughput (Skipping) d=0.7
Throughput (Conv) d=0.7
Throughput (Skipping) d=2
Throughput (Conv) d=2
d=0.7 seconds
Throughput (Conv) d=0.7
Throughput (Skipping) d=0.7
Throughput (Skipping) d=2
Infeasible Region for d=2
Throughput (Conv) d=2
d=2 seconds

FIG. 7

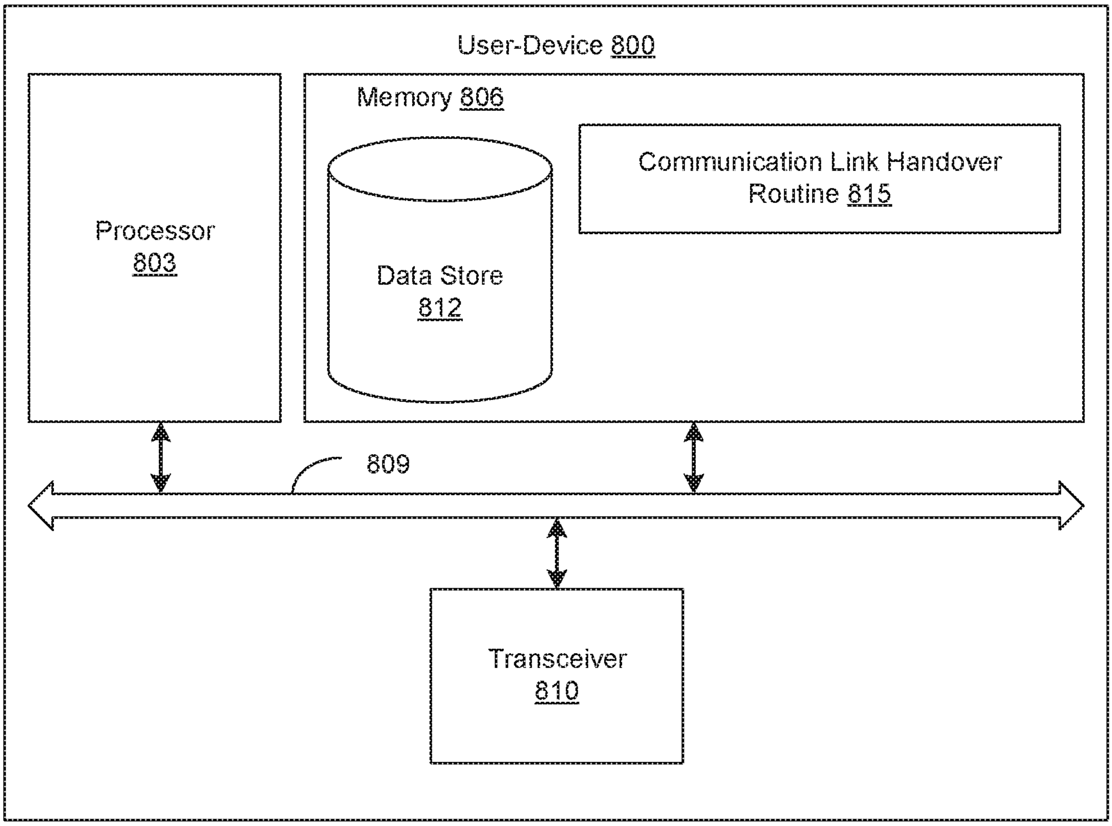
User-Device 800
Memory 806
Processor 803
Data Store 812
Communication Link Handover Routine 815
809
Transceiver 810

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2017/051714

A. CLASSIFICATION OF SUBJECT MATTER
INV. H04W36/32 H04W36/0Q
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H04W

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2016/073318 Al (AGUIRRE SERGIO [US]) 10 March 2016 (2016-03-10) paragraphs [0014], [0018] - [0020], [0036], [0067] - [0089]; figures 2-4, 5A-5D	1-15
X	US 2014/066074 Al (FOLKE MATS [SE] ET AL) 6 March 2014 (2014-03-06) paragraphs [0005] - [0012], [0014], [0041], [0043], [0044]	1-15
X	EP 2 892 278 Al (NEC CORP [JP]) 8 July 2015 (2015-07-08) paragraphs [0031], [0048]; figures 5,1,8	1-15
X	EP 2 950 586 Al (SAMSUNG ELECTRONICS CO LTD [KR]) 2 December 2015 (2015-12-02) paragraphs [0013] - [0019]; figures 2,3	1-15

-/--

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 June 2017	20/06/2017

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Domingos, Luis

1

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X, P	ARSHAD RABE ET AL: "Handover management in dense cellular networks: A stochastic geometry approach", 2016 IEEE INTERNATIONAL CONFERENCE ON COMMUNICATIONS (ICC), IEEE, 22 May 2016 (2016-05-22), pages 1-7, XP032921884, DOI: 10.1109/ICC.2016.7510709 [retrieved on 2016-07-12] cited in the application the whole document -----	1-15

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2017/051714

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		US 2014066074 Al	06-03-2014
		Wo 2012150880 Al	08-11-2012
EP 2892278 Al	08--07--2015	CN 104756549 A	01-07-2015
		EP 2892278 Al	08-07-2015
		JP 5928756 B2	01-06-2016
		JP W02014034090 Al	08-08-2016
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		US 2015373599 Al	24-12-2015
		WO 2014116063 Al	31-07-2014