# Abstract

Spatial modulation (SM) is a relatively new and attractive modulation technique for multi-antenna wireless systems. In SM, only one among $n_s = 2^m$ available transmit antennas, chosen on the basis of $m$ information bits, is activated at a time. A symbol from a conventional modulation alphabet (e.g., PSK) is transmitted through this chosen antenna. Space shift keying (SSK) is a special case of SM. In SSK, instead of sending a symbol from an alphabet, a signal known to the receiver, say a '+1', is transmitted through the chosen antenna. SSK has the advantage of simple detection at the receiver. In this thesis, we are concerned with the performance analysis of SSK in cooperative relaying systems. We consider decode-and-forward (DF) relaying protocol, where the relays decode the received signal and forward the decoded signal towards the destination. We consider three different models of cooperative relaying, namely, $i)$ dual-hop relaying, $ii)$ multi-hop relaying, and $iii)$ cooperative multicasting. We also consider a cyclic-prefix single carrier (CPSC) communication system in a point-to-point channel, and analyze the performance of both SM and SSK in that system under frequency selective fading.

**Dual-hop relaying:** First, we consider a cooperative relaying system consisting of a source node, a destination node, and a relay node. We consider two commonly used relaying techniques at the relay, namely, $i)$ incremental relaying, and $ii)$ threshold based relaying. We adopt selection combining at the destination. One way to perform selection combining operation is to use the knowledge of instantaneous signal-to-noise-ratio (SNR) as a metric for selection. However, in SSK, instantaneous SNR is difficult to be ascertained at the receiver side despite the availability of channel knowledge, because the transmit antenna index itself is not known. To overcome this difficulty, we propose a new metric specific to SSK to carry out selection among the competing links.

For the considered relaying schemes, we derive exact analytical expressions for the end-to-end average bit error probability (ABEP) for binary SSK (i.e., SSK with $n_s = 2$) in closed-form. Simulations validate the end-to-end ABEP predicted by the analytical expressions.

We then consider a dual-hop cooperative relaying system which consists of multiple relays. We propose a relay selection scheme for this system. In this system too, the destination adopts selection combining. Here, we use the proposed metric for both relay selection as well as selection combining. For this system, we derive an exact analytical expression for the end-to-end ABEP in closed-form for binary SSK. Analytical results agree with simulation results. For non-binary SSK (i.e., SSK with $n_s > 2$), we derive an approximate closed-form expression for the end-to-end ABEP. The analytical ABEP results follow the simulated ABEP results closely.

**Multi-hop relaying:** Next, we consider SSK in multi-hop multiple-input multiple-output (MIMO) networks. We consider two different systems of multi-hop cooperation, where each node has multiple antennas and employs SSK. In system I, a multi-hop diversity relaying scheme is considered. In system II, a multi-hop multi-branch relaying scheme is considered. In both the systems, we adopt DF relaying, where each relay forwards the signal only when it decodes correctly. We analyze the end-to-end ABEP and diversity order of SSK in both the systems. For binary SSK, our analytical ABEP expression is exact, and our numerical results show that the ABEPs evaluated through the analytical expression overlap with those obtained through simulations. For non-binary SSK, we derive an approximate ABEP expression, where the analytically evaluated ABEP results closely follow the simulated ABEP results. We present comparisons between the ABEPs of SSK and conventional PSK, and show the instances where SSK outperforms PSK. We also present the diversity analyses for SSK in systems I and II, which predict the achievable diversity orders as a function of system parameters.

**Cooperative multicast:** Next, we consider SSK in dual-hop DF cooperative multicast networks, where a source node communicates with multiple destination nodes with the help of relay nodes. We consider two different systems of cooperative multicast, namely, system III and system IV, where each node has multiple antennas and employs

SSK, and communication happens in two phases. In system III, multiple relay nodes exist between the source and destination nodes. The relays that decode correctly can forward the signal to the destination nodes. We propose and analyze a relay selection scheme for this system. In system IV, the destination nodes can act as relays. Specifically, the destination nodes that decode correctly from the signal received on the direct path from source in the first phase forward to other destination nodes that did not decode correctly. For system III, we derive an exact closed-form expression of end-to-end ABEP for binary SSK, and an approximate closed-form expression of ABEP for non-binary SSK. We also present the diversity analysis for system III which predicts the achievable diversity order as a function of the system parameters. For system IV, we derive approximate closed-form ABEP expressions. The ABEP results obtained through the approximate analysis closely follow those obtained from simulations for both binary and non-binary SSK.

**Single carrier system:** Finally, we study SM and SSK in CPSC systems on MIMO intersymbol interference (ISI) channels. We present a diversity analysis of MIMO-CPSC systems under SSK and SM signaling. Our analysis shows that the diversity order achieved by $(n_t, n_r)$ SSK scheme and $(n_t, n_r, \Theta_M)$ SM scheme in MIMO-CPSC systems under maximum-likelihood detection is $n_r$, where $n_t$ and $n_r$ denote the number of transmit and receive antennas, respectively, and $\Theta_M$ denotes the modulation alphabet of size $M$. Bit error rate simulation results validate this predicted diversity order. Simulation results also show that MIMO-CPSC with SM and SSK achieves better performance compared to MIMO-OFDM with SM and SSK.